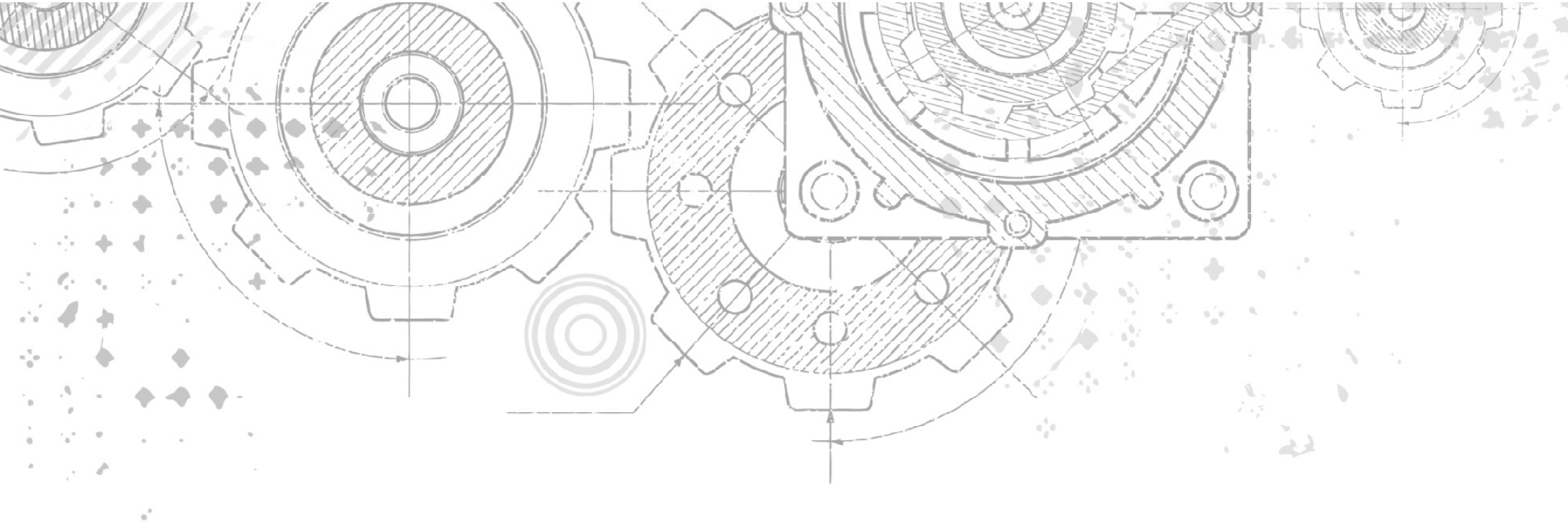

National Energy Efficiency Technology Roadmap Portfolio

March 2013

Enhanced PDF Functionality

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While the Bonneville Power Administration has funded and managed the overall development and maturation of the *National* (formerly *Northwest*) *Energy Efficiency Technology Roadmap Portfolio*, the effort would not have been possible without the active engagement of a diverse array of subject matter experts from organizations and institutions throughout North America. Since the beginning of this roadmapping project in late 2009, more than 200 participants representing 119 organizations have contributed approximately 5,120 hours and $1,100,000 worth of voluntary input. Their expertise is essential to this project.

Members of the Regional Emerging Technology Advisory Committee (RETAC) played a key role the roadmap's creation. Those members include representatives from Bonneville Power Administration, Northwest Power and Conservation Council, Northwest Energy Efficiency Alliance, Electric Power Research Institute, Pacific Northwest National Laboratory, Washington State University Energy Program, Energy Trust of Oregon, Puget Sound Energy, Snohomish Public Utility District, Seattle City Light, Idaho Power, and Avista. RETAC member input was critical in laying the groundwork for the Roadmap Portfolio and has been as important as the project has matured.

Thanks as well to the project team, who worked behind the scenes to plan, coordinate, analyze, evaluate, revise, and prepare everything needed to continue fine-tuning this portfolio. Without the help of contractors from the Engineering and Technology Management Department at Portland State University, the Washington State University Energy Program, and Livingston Energy Innovations, this roadmap would be much less robust than it is today.

Finally, a special thanks to our partners at the Electric Power Research Institute who brought their collective expertise to bear in 2012 to evaluate the current status of R&D projects and programs for this latest version. EPRI expertise and support was also essential in convening the National Energy Efficiency Technology Roadmapping Summit in Portland (Aug. 8 and Sep. 24–27, 2012).

There is still much collaborative work to be done to improve our understanding of the current energy efficiency technology research landscape but we are making strides in the right direction and we truly appreciate the dedication and contributions of all who have been a part of this important endeavor.

For more information about the National Energy Efficiency Technology Roadmap Portfolio, contact:

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FORWARD

Technology has played a central role in the Northwest's development, from the Federal Columbia River Power System to technology giants like Boeing, Microsoft and Intel to thousands of businesses, universities and laboratories. In the Northwest, irrigation is high tech.

This savvy has allowed the region to meet half of its load growth through cost-effective investments in energy efficiency for more than thirty years. Through the leadership of the region's utilities, labs, universities, energy organizations and private businesses, the Northwest has been able to successfully deliver energy efficiency as a reliable resource.

The Northwest Power and Conservation Council's *Sixth Power Plan* calls for roughly 85 percent of the region's load growth to be met with energy efficiency by 2030. To meet these goals, we must find ways to increase the adoption rates of existing products and services. At the same time, we must also strategically target the region's research and development resources into efforts that will produce the technologies needed to enable the products of tomorrow.

In December 2009 thirty-five experts from twenty organizations pooled their efforts to develop an energy efficiency technology roadmap portfolio that would define a research agenda for the Northwest. The results of the intensive ten-week effort have been expanded and refined through additional workshops and the integration of critical comments from experts beyond the region. Revised drafts of the *National* (formerly *Northwest*) *Energy Efficiency Technology Roadmap Portfolio* have been released in March and July 2010, March 2011, and March, August, and September 2012, and January 2013. The portfolio will always be a draft; it is intended as a living document, continuously refined as we move forward.

There are two notable additions to the *Roadmap* Portfolio commencing with the March 2012 version. We have expanded the roadmaps into two important industrial product and service areas: food processing and combined heat and power (CHP) technologies. We have also created a new appendix of existing R&D programs (Appendix B) to provide expanded and updated information previously contained in the individual "R&D Program Summaries" pages. Beginning with the March 2013 version, the residential and commercial sector R&D program summary pages identify key research questions for most R&D programs.

Far more minds are needed to contribute; hence the document is public, freely available for use by others in process, form, and content. As always, we are distributing this draft with a request: Please evaluate these findings with a critical mind and send us your comments. We are especially interested in filling in any holes in regard to existing research and development programs. We are not interested in duplicating efforts already underway elsewhere.

We will be collecting feedback on this draft on an ongoing basis. Any and all comments can be sent directly to our project manager, James V. Hillegas-Elting (jvhillegas@bpa.gov, 503.230.5327).

Sincerely,

Terry Oliver
Chief Technology Innovation Officer
Bonneville Power Administration

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Special Introduction: March 2013

The March 2013 version of the *National Energy Efficiency Technology Roadmap Portfolio* (*Roadmap Portfolio*) is significantly revised and expanded and reflects the input of nearly 200 subject matter experts from throughout North America convened during the National Energy Efficiency Technology Roadmapping Summit held in Portland, Oregon, September 24–27, 2012. The most significant changes to this version compared to the March 2012 version include:

- Thoroughly updated and revised versions of all five residential and commercial sector roadmaps;
- Key research questions specified for most R&D program titles within the residential and commercial sector roadmaps;
- Updated organizational chart to reflect input gathered during the September 2012 summit;
- Developed the first version of a cross-cutting Integrated Systems roadmap (to be found in the HVAC section); and
- Removed the regional R&D program prioritization in expectation of a revised version (that is projected to be published as a separate addendum later in 2013).

After receiving numerous suggestions from Roadmapping Summit participants to develop an Integrated Systems roadmap, this option is now at the forefront of ideas for future expansion of the portfolio (though no definitive plans have been made as of the date of publication).

Purpose of the Roadmap Portfolio

Technology roadmapping is a tool that enables organizations to manage time and resource investments more thoroughly and accurately in response to increasing complexity and the accelerated pace of change. The defining elements of the roadmapping process are:

1. Solicit stakeholder expertise in a structured manner;
2. Distill this expertise within an easy-to-navigate deliverable, such as a diagram, document or website; and
3. Use the resultant deliverable to help guide planning.

The roadmapping approach is defined by some core elements but there is wide variation in how a given organization applies them. The result is that technology roadmaps come in an array of formats and are created for a range of purposes. These variations reflect the different missions, cultures, and strategic goals of the organization(s) developing a given roadmap. As long as the roadmap fulfills the purposes that stakeholders intended, it can be considered a useful tool.

The *Roadmap Portfolio* exists to define (and refine) a technology research agenda for the medium and long-term (five to twenty years) to guide institutional and regional investment strategies. It does so by identifying the landscape of energy efficiency R&D programs linked directly to desired technology characteristics and by tracking research needs that are already being addressed. This latter function provides confidence to BPA and other stakeholders that R&D project funding is not redundant and that resources are optimized within a strategic plan.

The *Roadmap Portfolio* provides a snapshot of stakeholders' current perspectives on:

1. Key drivers (environmental/global, market, policy and regulatory, and technology innovation) affecting the nation in regard to energy efficiency;
2. Products/services needed to address identified drivers;
3. Technologies needing development to bring non-existing products and services to the marketplace; and
4. Gaps in existing R&D programs designed to address identified technology needs.

Ultimately, the goal of identifying and prioritizing technology R&D gaps allows for a more rational allocation of limited funding and resources by organizations such as the BPA, national labs, research universities, private businesses, and venture capitalists.

With its focus on R&D programs that seek to address business challenges and opportunities in the five-to-twenty-year time horizon, the *Roadmap Portfolio* fulfills another important need. It is distinct from—but complementary to—the efforts of teams at BPA, the Northwest Energy Efficiency Alliance (NEEA), and elsewhere whose work involves "emerging technologies." This work tends to be focused more on the nearer-term time horizon (zero to three years) than the R&D programs identified in the *Roadmap Portfolio*.

BPA's Energy Efficiency Emerging Technology (E3T) team and NEEA lead the Pacific Northwest's efforts to coordinate regional emerging technology research. This collaboration was another recommendation of the Northwest Energy Efficiency Taskforce in 2009 (more information below) and is also done in collaboration with national organizations such as the Consortium for Energy Efficiency and the California Emerging Technologies Coordinating Council. These groups research and analyze products and services with the potential to deliver significant energy savings but that may be facing market, behavioral, regulatory, or other barriers to large-scale introduction. The *Roadmap Portfolio* project team further defines *emerging technology* as any technology that is already available in the marketplace but that is facing one or more barriers to widespread adoption.

Both the *Roadmap Portfolio* and emerging technologies work strives to bridge "chasms" that exist between an idea and its implementation as a proven energy-efficient product or service within utility programs. Tracking R&D programs through the *Roadmap Portfolio* aids the efforts of emerging technologies teams by enabling the more rapid identification of technologies with energy savings potential; in turn, emerging technologies teams contribute to the work of utility programs staff by validating this potential and providing the necessary quantitative data to determine if a given product or service is worth implementing or incentivizing.

Figure 1 illustrates how the *Roadmap Portfolio* project and emerging technology research are both necessary strategies to help "fill the pipeline" of energy-efficient products and services for utility programs. This diagram also correlates this process with the Department of Energy's Technology Readiness Levels (TRLs) and identifies two potential "chasms" that can be barriers to implementing energy-efficient technologies.

Another important purpose of the *Roadmap Portfolio* that deserves mention is that it is focused on *technology* R&D programs. There are many other important considerations that propel or hinder the widespread adoption of energy efficiency products and services, such as market conditions, human behavior, regulations, policies, standards, and education/training. Readers will find these non-technology-related considerations in the *Roadmap Portfolio* primarily within the Driver or Capability Gap categories, but they generally do not fall within the purview of *technology* R&D programs. Other institutions have developed or are developing roadmaps that focus specifically on these other considerations. The *Roadmap Portfolio* will include citations to and updates about these other roadmaps as information becomes available. Examples include the American National Standards Institute (ANSI) Energy Efficiency Standardization Coordination Collaborative (EESCC) roadmapping project and the Alliance to Save Energy's energy efficiency policy recommendations of February 2013 listed below.

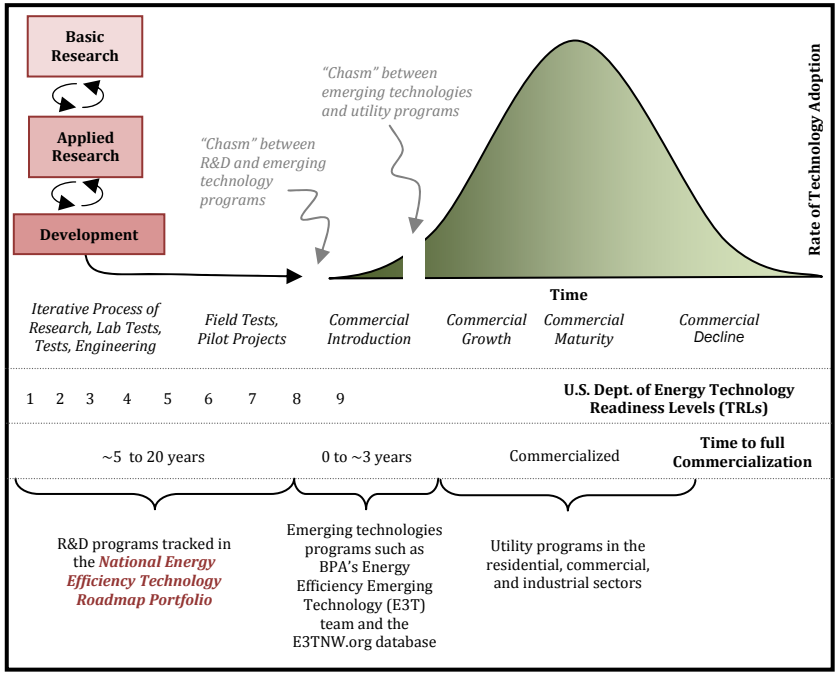


Figure 1: Energy Efficient Technology Commercialization Process.

(Adapted from Institute for Building Efficiency, "Advancing Energy Efficiency Technology: California Helps Blaze the Trail: Insights from the Emerging Technologies Coordinating Council 2010 Summit," n.d. (ca. Nov. 2010), http://www.institutebe.com/Building-Efficiency-Events/ettc-summit-2010.aspx.)

Background to the Roadmap Portfolio

From the beginning, development of the *Roadmap Portfolio* has been a needs-driven, collaborative effort that reflects the input and expertise of a diverse range of stakeholders. In 2008 and 2009 a group of executives representing regional utilities and stakeholders convened as the Northwest Energy Efficiency Taskforce (NEET) to explore how to deliver electricity conservation savings more effectively and efficiently. Among NEET's recommendations was that BPA and NEEA improve

coordination and collaboration on energy efficiency emerging technology research.

As an initial step in this process, stakeholders formed a representative group of subject matter experts as the Regional Emerging Technology Advisory Committee (RETAC). One of the RETAC's first projects was to initiate the development of an updateable energy efficiency technology roadmap that would describe the present landscape of research programs needed to enable technology characteristics that fill capability gaps and, thereby, address key economic, social, environmental, regulatory, and other drivers.

BPA staff had created an agency-specific energy efficiency roadmap in the mid-2000s, but the RETAC's charge was for BPA to broaden the scope of this effort. This work helped inform the initial stages of the creation of the *Northwest Energy Efficiency Technology Roadmap* which, as its title indicates, was motivated by a scope that expressly incorporated the breadth of regional business challenges and opportunities.

From its inception the project team has envisioned the portfolio as a live, working document to be continually refined and revised to reflect stakeholder needs and the ever-evolving technology landscape. Northwest-focused editions of the portfolio were published in 2010, 2011, and early 2012. The March 2012 version included food processing and combined heat and power roadmaps and a new appendix (Appendix B) to track existing R&D projects identified in the roadmap pages. With the success of the project and increased interest from colleagues outside of the region, in 2012 the project team expanded the scope by convening the National Energy Efficiency Technology Roadmapping Summit (more information on this event below).

In the process of identifying gaps in existing energy efficiency R&D programs, roadmapping participants in 2010 also identified a list of products and services that were already available in the marketplace but not widely adopted due to various technical and/or market barriers—the "emerging technologies" described above. While addressing this group of products and services was not the primary purpose of the roadmapping endeavor, a workshop was held to articulate:

1. Barriers to the wider adoption of existing products/services; and
2. Necessary components to future market intervention programs and other initiatives to increase adoption rates for these targeted products/services.

The findings articulated by participants in this workshop can be found in Appendix A, specifically Appendix A4, "Workshop 3 (Market Interventions, Programs, Other Initiatives)."

BPA has served in a leadership role in the development and continued refinement of the *Roadmap Portfolio* because of the important role the agency plays in conservation, marketing, transmission, and environmental stewardship; however, the agency does not "own" the process or the product. The portfolio would be of significantly less value if it were not for the input, support, and critical feedback at every stage of the process from each of the individuals and institutions identified in the "Support Staff" and "Workshop Participants" pages above. Since the beginning of this roadmapping project in late 2009, more than 200 participants representing 119 organizations have contributed approximately 5,120 hours and an estimated $1,100,000 worth of voluntary input.

BPA's Office of Technology Innovation uses these roadmaps to guide its annual solicitation for proposals for energy efficiency R&D projects. This annual solicitation occurs in March; proposals not linked to technology needs identified in the roadmap are not eligible for awards. Because these roadmaps are shared public resources, any organization can also use them to guide their own research efforts with some confidence that their work fits into a larger research agenda crafted and vetted by technical experts from across the country.

By creating a regional technology roadmap portfolio that has now expanded to be national in scope, the Northwest has taken an important step toward the goal of creating continuity between its R&D efforts to bring non-existing technologies to market, ongoing work in emerging technologies, and present and future market intervention strategies.

Both the *Roadmap Portfolio* and the work of emerging technology organizations are critically important in realizing energy savings: As recent studies from the Energy Trust of Oregon and the Northwest Power and Conservation Council's NW Resource Adequacy Forum conclude, regional energy efficiency targets will fall short before 2020 without robust efforts to identify and bring to market a steady stream of increasingly more efficient technologies.

At the national level, the Alliance to Save Energy's February 2013 report *Energy 2030: Doubling U.S. Energy Productivity by 2030* recognizes the critical role that government plays in complementing private sector energy productivity and market adoption of energy-efficient technologies. Because "private R&D budgets are small in many sectors related to energy productivity in part due to the fragmented markets and industry structures and to the spillover of knowledge," this report notes,

> *government support both for R&D and for a wide range of deployment programs has been critical to advances in energy productivity. Often these programs have been most effective in concert: R&D support helps develop technologies, technical assistance and incentives assist early market introduction, information programs spur broad commercialization, and standards ensure that all consumers benefit and push markets forward toward further innovation (p. 22).*

National Energy Efficiency Technology Roadmapping Summit 2012

The National Energy Efficiency Technology Roadmapping Summit convened in Portland, Oregon, September 24–27, 2012, with a preparatory workshop held August 8. Planning and implementing this event involved close collaboration among BPA, the Electric Power Research Institute (EPRI), Portland State University Engineering and Technology Management Department, Washington State University Energy Program, and NEEA. Summit participants included government entities, national laboratories, academic and other research institutions, public and investor-owned utilities, vendors, non-profit organizations, and others. (Names of Summit workshop participants have been integrated into the list on the preceding pages.)

Subject matter experts volunteered their time to update and expand energy efficiency technology roadmaps within the residential and commercial sectors. They further strengthened the roadmaps by articulating key research questions for most R&D programs listed in the *Roadmap Portfolio*. In so doing, workshop participants helped refine a resource used to optimize research and development investments by limiting redundant spending and identifying opportunities for inter-organizational collaboration.

In conjunction with the roadmapping workshops, EPRI organized four full days of expert panel presentations on cutting-edge technologies. The two-fold purpose of these presentations was: 1) to convene a group of expert speakers to provide brief and informative highlights and overviews of noteworthy research and development efforts; and 2) to provide a venue in which national experts could network with one another, share ideas and achievements, and gain inspiration and insights that could be applied in the corresponding roadmapping workshop.

See Appendix A for Roadmapping Summit schedules, agendas, and workshop minutes. For Summit presentations and videos, see http://online.etm.pdx.edu/bpa_summit/home.html.

While this roadmapping initiative commenced in the Pacific Northwest, expanding the collaboration beyond the region during 2012 was the first step in developing a resource that will provide benefits to many other institutions and constituencies. Including the pre-Summit workshop held August 8, 2012, the Summit brought together about 180 experts representing 101 organizations from across the United States and British Columbia. Collectively, these participants voluntary provided approximately 4,200 hours and $950,000 of in-kind contributions to the EE technology roadmapping effort.

Selected Sources

The list below identifies sources for additional details on some of the background information provided above.

Alliance to Save Energy, Alliance Commission on National Energy Efficiency Policy, *Energy 2030: Doubling U.S. Energy Productivity by 2030*, Feb. 7, 2013, http://ase.org/sites/default/files/full_commission_report.pdf.

"E3T: Energy Efficiency Emerging Technologies," http://e3tnw.org/.

Energy Trust of Oregon, "Briefing Paper: Energy Efficiency Programs," June 8, 2012, http://energytrust.org/library/meetings/board/120608_Board_Strategic_Planning_Workshop.pdf.

Jonathan Livingston, Jack Callahan, Ryan Fedie, Robert Penney, and Jack Zeiger, "The E3T Framework: Fast-Tracking Emerging Technology Development in the Pacific Northwest," 2010 ACEEE Summer Study on Energy Efficiency in Buildings, http://www.aceee.org/files/proceedings/2010/data/papers/2041.pdf.

"National Energy Efficiency Technology Roadmapping Summit, September 24-27, 2012, DoubleTree Hotel, Portland, Oregon," http://online.etm.pdx.edu/bpa_summit/home.html.

"NEET Report: Northwest Energy Efficiency Taskforce Report, Recommendations, Action Plan," Oct. 2009, http://www.nwcouncil.org/energy/neet/NEET%20Report%20October%202009.pdf.

"Northwest Energy Efficiency Taskforce," http://www.nwcouncil.org/energy/neet/.

NW Adequacy Forum, "Pacific Northwest Power Supply Adequacy Assessment for 2017, Final Report," Nov. 21, 2012, http://www.nwcouncil.org/news/2012/12/4.pdf.

"Regional Emerging Technology Advisory Committee," https://conduitnw.org/Pages/Group.aspx?rid=29.

U.S. Department of Energy Advanced Manufacturing Office, "Technology Readiness Levels (TRLSs)," Dec. 2011, http://www1.eere.energy.gov/manufacturing/financial/trls.html.

Energy Efficiency Roadmapping Projects & Strategic Planning Documents

The lists below are intended to be broadly representative rather than exhaustive and will be updated as new information becomes available.

Energy Efficiency Technologies Roadmapping

Electric Power Research Institute (EPRI)

Power Delivery and Utilization Sector Roadmaps, April 2012, http://mydocs.epri.com/docs/ CorporateDocuments/Roadmaps/PDU%20Roadmap_2012-04.pdf.

Oak Ridge National Laboratory (ORNL)

Research and Development Roadmap for Water Heating Technologies, prepared by Navigant Consulting, Inc., Sep. 30, 2011, http://www.ornl.gov/ci/ees/etsd/btric/pdfs/ WaterHeatingTechnologiesRoadmap_9-30-2011_FINAL.pdf.

Lawrence Berkeley National Laboratory (LBNL)

High-Performance Data Centers: A Research Roadmap, July 2003, http://hightech.lbl.gov/ documents/ datacenters_roadmap_final.pdf.

U.S. Department of Energy Office of Energy (DOE) Efficiency and Renewable Energy (EERE)

Building Technologies Office Strategic Plans, http://www1.eere.energy.gov/buildings/residential/ba_strategic_plan.html.

Solid-State Lighting Research and Development: Multi-Year Program Plan, prepared by Bardsley Consulting (and others), April 2012, http://apps1.eere.energy.gov/buildings/publications/pdfs/ ssl/ssl_mypp2012_web.pdf.

Buildings R&D Breakthroughs: Technologies and Products Supported by the Building Technologies Program, April 2012, http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/rd_ breakthroughs.pdf.

Summary of Gaps and Barriers for Implementing Residential Building Energy Efficiency Strategies, Aug. 2012, http://apps1.eere.energy.gov/buildings/publications/pdfs/building_americ a/49162.pdf.

Windows and opaque building envelope roadmaps (as of November 2012, these roadmaps were soon to be published at http://www.eereblogs.energy.gov/buildingenvelope/).

Energy Efficiency Standards Roadmapping

American National Standards Institute (ANSI) Energy Efficiency Standardization Coordination Collaborative (EESCC)

As of March 2013, the ANSI EESCC is working with stakeholders to develop an energy efficiency standardization roadmap within the built environment. This roadmap will provide an overview of the energy efficiency standardization landscape including existing or in-development standards, codes, guidelines, and conformance programs and identify perceived gaps in energy efficiency standardization and conformance activities.

ANSI EESCC energy efficiency standards roadmap, http://www.ansi.org/standards_activities/standards_boards_panels/eescc /overview.aspx?menuid=3.

Other Energy Efficiency Roadmapping

Oregon Built Environment & Sustainable Technologies Center (Oregon BEST)

Oregon BEST regularly convenes Agenda Development Forums of subject matter experts to develop prioritized research agendas to achieve energy efficiency and environmental performance goals. To date, Oregon BEST has published two reports in their Research Agenda Series.

"Deep Retrofits Research Agenda," Nov. 2012, http://oregonbest.org/sites/default/files/consortium/adf2012-09_deepretrofitsresearchagenda_lowresv2.pdf.

"Living Building Challenge Materials Research Agenda," Jan. 2013, http://oregonbest.org/sites/default/files/consortium/adf2012-11_lbcmaterialsresearchagenda.pdf.

Energy Efficiency Strategic Planning Documents

Alliance to Save Energy (ASE)

In February 2013, the ASE published energy efficiency policy recommendations written by its Alliance Commission on National Energy Efficiency Policy, *Energy 2030: Doubling U.S. Energy Productivity by 2030*. This reported concluded that "the U.S. can double its energy productivity by 2030 using cost-effective technologies and practices. Benefits to the nation from achieving this goal would be monumental . . . net benefits could be over $1,000 a year in average household savings in utility and transportation costs, over a million added jobs, a one-third reduction in carbon dioxide emissions, and a similar reduction in oil imports." To achieve these outcomes, the ASE "urges policy makers and the private sector to take immediate and concerted action" to "Unleash Investment in energy productivity throughout the economy, Modernize Regulations and Infrastructure to improve energy productivity, and Educate and Engage consumers, workers, business executives, and government leaders on ways to drive energy productivity gains."

The ASE believes that "these strategies can be implemented without burdensome *mandates* or massive government spending. To achieve this goal and its benefits, some public-private partnerships, and targeted government investments will be needed, and some rules will need to be reformed and strengthened."

Energy 2030: Doubling U.S. Energy Productivity by 2030, Feb. 7, 2013, http://ase.org/sites/default/files/full_commission_report.pdf.

Energy 2030 Recommendations, http://ase.org/resources/energy-2030-recommendations.

Energy 2030 Research Reports, http://ase.org/resources/ee-commission-report-summaries.

California Public Utilities Commission (CPUC)

The CPUC launched a strategic effort in 2007 to achieve ambitious energy efficiency and greenhouse gas emission reductions by transforming the marketplace. The CPUC worked closely on this project with the state's regulated utilities—Pacific Gas and Electric Company, Southern California Edison Company, San Diego Gas & Electric Company, and Southern California Gas Company—and more than 500 individuals and organizations. The result was a roadmap for energy efficiency through and beyond 2020 that sets forth a long-term vision and goals for each economic sector and identification of near-term, mid-term and long-term strategies.

California Energy Efficiency Strategic Plan, http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/eesp/.

California Energy Efficiency Strategic Plan, update Jan. 2011, http://www.energy.ca.gov/ab758/documents/CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

California Energy Efficiency Strategic Plan—HVAC Action Plan, http://www.cpuc.ca.gov/NR/rdonlyres/25B56CBE-7B79-41BC-B1C0-AE147F423B19/0/HVACActionPlan.pdf.

California Energy Efficiency Strategic Plan—Lighting Action Plan, http://www.cpuc.ca.gov/NR/rdonlyres/BE058656-3913-4DDD-92D5-60E82DD6AF0C/0/Lightingchapter_CAEnergyEfficiencyStrategicPlan_Jan2011.pdf.

California Energy Efficiency Strategic Plan—Zero Net Energy Commercial Building Action Plan, http://www.cpuc.ca.gov/NR/rdonlyres/6C2310FE-AFE0-48E4-AF03-530A99D28FCE/0/ZNEActionPlanFINAL83110.pdf.

National Action Plan for Energy Efficiency

The U.S. Environmental Protection Agency and Department of Energy co-facilitated the National Action Plan for Energy Efficiency from 2005 to 2010. It was "a private-public initiative to create a sustainable, aggressive national commitment to energy efficiency through the collaborative efforts of gas and electric utilities, utility regulators, and other partner organizations. Such a commitment can take advantage of large opportunities in U.S. homes, buildings, and schools to reduce energy use, save billions on customer energy bills, and reduce the need for new power supplies."

Overseeing the creation of the Action Plan was a group of more than sixty leading gas and electric utilities, state agencies, energy consumers, energy service providers, environmental groups, and energy efficiency organizations. The group "identified key barriers limiting greater investment in cost-effective energy efficiency, made five key policy recommendations to overcome the barriers, and documented policy and regulatory options for greater attention and investment in energy efficiency."

National Action Plan for Energy Efficiency (last updated Oct. 17, 2012), http://www.epa.gov/cleanenergy/energy-programs/suca/resources.html.

National Action Plan for Energy Efficiency, *Vision for 2025: A Framework for Change*, Nov. 2008, http://www.epa.gov/cleanenergy/documents/suca/vision.pdf.

Energy Efficiency Technology R&D Funding Institutions

The table below identifies energy efficiency technology R&D funding institutions and provides overviews of their request for proposal (RFP) processes and schedules. Though not exhaustive, this list is current at the time of publication based upon available information and is subject to change at any time.

As of the date of publication, BPA and EPRI staff continue to reach out to representatives of other R&D funding institutions with the complementary goals of:

- Identifying opportunities to use portfolio content to decrease the risk of redundant and unnecessary spending by coordinating R&D expenditures and efforts where feasible;
- Determining effective ways to expand and enhance portfolio content in efficient and mutually-beneficial ways; and
- Disseminating accurate and timely R&D RFP solicitation information and schedules to interested institutions, organizations, and firms.

Institution	Website	Scope	RFP Schedule
Bonneville Power Administration (BPA) Office of Technology Innovation	http://www.bpa.gov/Doing%20Business/TechnologyInnovation/Pages/default.aspx	"One key to BPA's success is making a firm connection with the business and technology challenges facing the utility industry. Technology roadmaps capture the logic and business framework for research and development. The roadmaps describe the specific BPA-related factors driving technology needs and identify the areas offering the greatest potential. BPA's Technology Innovation uses a cross agency Council of executives and technologists to guide its research and development efforts. BPA's Technology Innovation initiative has an annual cycle of portfolio funding based on strategic needs identified in the agency's technology roadmaps."	Annual RFP opens early March
California Energy Commission (CEC) Public Interest Energy Research (PIER) Program	http://www.energy.ca.gov/contracts/pier.html	Offers funding in the areas of Buildings End-Use Energy Efficiency; Energy Innovations Small Grant (EISG) Program; Energy Technology Systems Integration; and the Renewable Energy Research Area.	See http://www.energy.ca.gov/contracts/pier_upcoming.html
State of Delaware Energy Efficiency Investment Fund	http://www.dnrec.delaware.gov/energy/information/otherinfo/Pages/EnergyEfficiencyInvestmentFund.aspx	The Energy Efficiency Investment Fund (EEIF) was created to help Delaware businesses make strategic investments in capital equipment and facility upgrades that will help decrease operating costs, reduce energy consumption, and improve environmental performance. The program offers funding for technical assistance, as well as competitively awarded grants and loans for implementation of energy efficiency projects."	"The EEIF program anticipates releasing solicitations on an annual basis"

INSTITUTION	WEBSITE	SCOPE	RFP SCHEDULE
National Science Foundation (NSF) Transformative Research	http://www.nsf.gov/about/transformative_research/	"As part of the larger Federal research and development effort, NSF has a comprehensive, overarching mandate to help keep all the fields and disciplines of science and engineering research healthy and strong. NSF accomplishes this through programs that support basic research proposed by individual investigators or collaborative groups of investigators. In addition to funding research through core disciplinary programs, NSF also provides support for facilities, equipment, instrumentation, centers of research, and activities such as workshops that help to advance fields of science."	See http://www.nsf.gov/about/transformative_research/
New York State Energy Research and Development Authority (NYSERDA) Energy Efficiency and Renewable Programs	http://www.nyserda.ny.gov/en/Energy-Efficiency-and-Renewable-Programs.aspx	"Conducting a multifaceted energy and environmental research and development program has been a central responsibility at NYSERDA since its inception in 1975. NYSERDA's R&D Program supports the development and commercialization of innovative energy and environmental products, technologies, and processes that improve the quality of life for New York's citizens and help New York businesses to compete and grow in the global economy." NYSERDA's Research and Development Program Areas include Energy Resources; Transportation and Power Systems; Energy and Environment Markets; Industry; Buildings; and Transmission and Distribution.	See http://www.nyserda.ny.gov/Energy-Innovation-and-Business-Development.aspx
Ontario Power Authority Industrial Accelerator Program	http://www.industrialaccelerator.ca/	"Industrial Accelerator is designed to assist eligible transmission-connected companies to fast track capital investment in major energy-efficiency projects. The five-year program will provide attractive financial incentives to encourage investment in innovative process changes and equipment retrofits so that the rate of return is competitive with other capital projects. In exchange, participants will contractually commit to delivering specific conservation targets within a set period of time and to maintaining them over the expected life of the project."	See http://www.industrialaccelerator.ca/
U.S. Department of Defense Environmental Security Technology Certification Program (ESTCP)	http://www.serdp.org/	"ESTCP releases at least one solicitation each fiscal year. Researchers from Federal organizations, universities, and private industry can apply for ESTCP funding. All proposals must respond to a Topic Area associated with the solicitation. ESTCP projects are formal demonstrations in which innovative technologies are rigorously evaluated. ESTCP demonstrations are conducted at DoD facilities and sites to document improved efficiency, reduced liability, improved environmental outcomes, and cost savings."	See http://www.serdp.org/Funding-Opportunities/ESTCP-Solicitations
U.S. Department of Defense Strategic Environmental Research and Development Program (SERDP)	http://www.serdp.org/	"SERDP issues two annual solicitations. The Core Solicitation seeks proposals for basic and applied research, and advanced technology development. Core projects vary in cost and duration, consistent with the scope of the work proposed. The SERDP Exploratory Development (SEED) program is designed to investigate innovative approaches that entail high technical risk or require supporting data to provide proof of concept. SEED projects are limited to not more than $150,000 and are approximately one year in duration. SEED projects that are successful are considered for additional follow-on funding. All submissions must be in response to a Statement of Need (SON) associated with the solicitation. Core and SEED solicitations have different SONs and different due dates."	See http://www.serdp.org/Funding-Opportunities/SERDP-Solicitations

INSTITUTION	WEBSITE	SCOPE	RFP SCHEDULE
U.S. Department of Energy	http://energy.gov	"The mission of the Energy Department is to ensure America's security and prosperity by addressing its energy, environmental and nuclear challenges through transformative science and technology solutions."	See http://energy.gov/public-services/funding-opportunities
U.S. Department of Energy Advanced Research Projects Agency–Energy (ARPA–E)	http://arpa-e.energy.gov	"ARPA-E funds technology-focused, applied research and development aimed at creating real-world solutions to important problems in energy creation, distribution, and use. . . . ARPA-E issues periodic Funding Opportunity Announcements (FOAs), which are focused on overcoming specific technical barriers around a specific energy area. ARPA-E also issues periodic OPEN FOAs to identify high-potential projects that address the full range of energy-related technologies, as well as funding solicitations aimed at supporting America's small business innovators."	See http://arpa-e.energy.gov/?q=programs/apply-for-funding
U.S. Department of Energy Office of Energy Efficiency & Renewable Energy (EERE)	http://www.eere.energy.gov/	"The Office of Energy Efficiency and Renewable Energy (EERE) works with business, industry, universities, and others to increase the use of renewable energy and energy efficiency technologies. One way EERE encourages the growth of these technologies is by offering financial assistance opportunities for their development and demonstration."	See http://www1.eere.energy.gov/financing/
U.S. Department of Energy Office of Energy Efficiency & Renewable Energy (EERE) Building America Program	http://www1.eere.energy.gov/buildings/residential/ba_index.html	"Since 1995, the U.S. Department of Energy's Building America program has provided research and development of building innovations to the residential construction and remodeling industry. As a national center for world class research, Building America develops market-ready solutions through partnerships with building and remodeling industry leaders, nationally recognized building scientists, and the national laboratories."	See http://www1.eere.energy.gov/financing/

The *Roadmap Portfolio* is a reference tool designed to be a living, working document. It was not crafted with any expectation that it would be read from beginning to end like a traditional report or narrative. Rather, its design allows for quick reference technology development research agendas in relation to specific energy efficiency products and services.

The content herein is organized into eight sections, with multiple product/service-level roadmaps within each section. The eight sections are:

1. Building Design/Envelope
2. Lighting
3. Electronics
4. Heating, Ventilation, and Air Conditioning
5. Sensors, Meters, and Energy Management Systems
6. Industrial Food Processing
7. Combined Heat & Power

Appendix A contains process documents for all of the technology roadmapping workshops held to date.

Appendix B contains more information, when available, about existing R&D programs identified in the portfolio.

Disclaimer

Some roadmaps, project summaries, and appendix pages identify specific vendors, commercial products, or proprietary systems and technologies. BPA, its partner institutions, and other stakeholders make these references solely for context; these references do not constitute endorsement on the part of BPA, the Department of Energy, or any stakeholder involved in the creation and refinement of these roadmaps.

Roadmap Portfolio "Swim Lane" Definitions

Roadmap diagrams are composed of the following four "swim lanes":

Drivers: Critical factors that constrain, enable, or otherwise influence organizational decisions, operations, and strategic plans. These factors can include: existing or pending regulations and standards; the environment; market conditions and projections; consumer behavior and preference; and organizational goals and culture, among others.

Capability Gaps: Barriers or shortcomings that stand in the way of meeting drivers.

Technology Characteristics: Specific technical attributes of a product or service that are necessary to overcome capability gaps.

R&D Programs: The iterative process undertaken at universities, national laboratories, some businesses, and related organizations to generate new ideas for products and services, develop models and prototypes, evaluate these in laboratory settings, and conduct engineering and production analyses with the goal of delivering the product or service to the marketplace. Within the *Roadmap Portfolio* the generic abbreviation "R&D" is to be understood as including, when appropriate, design, deployment, and demonstration in addition to research and development.

What is the difference between a "Technology Characteristic" and a "Capability Gap?"

A food processing company finds that the machine it currently uses to peel potatoes removes a significant amount of the flesh of the potato. Removing too much of the flesh reduces the yield of each processed potato and this reduced yield means that the company is not getting as much saleable product out of each unit of potatoes. The company must also pay increased costs to dispose of their wastes.

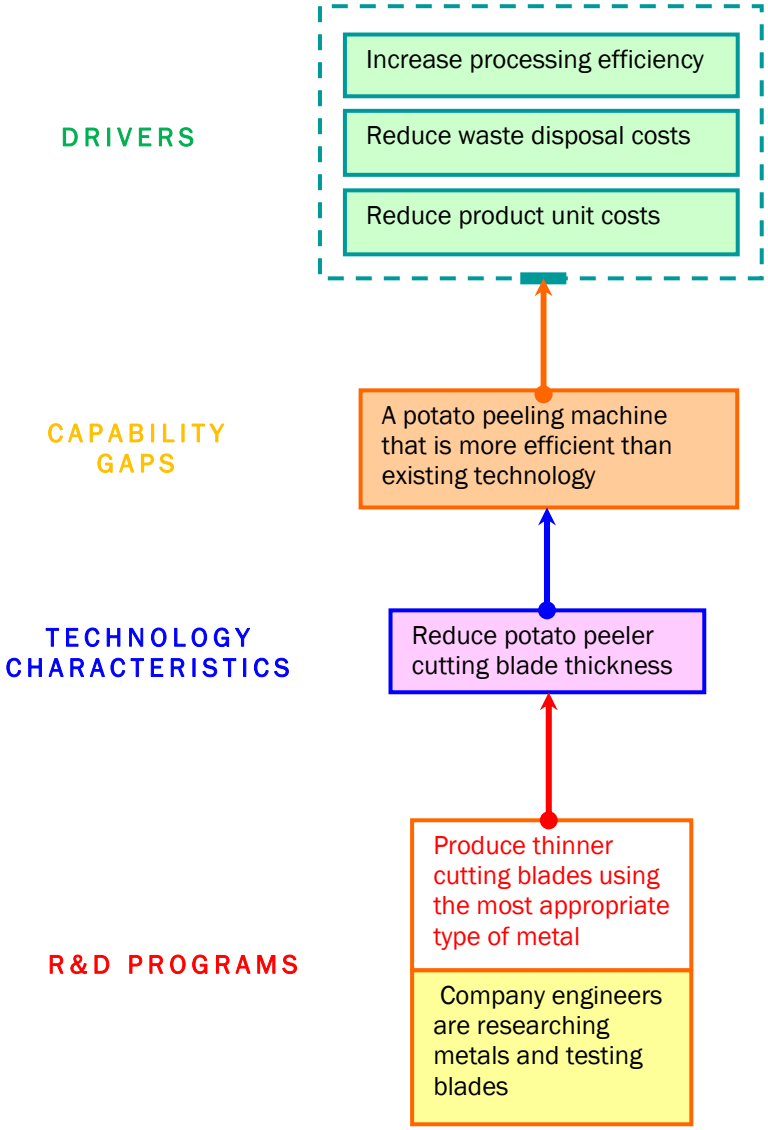
Faced with this situation, the company is facing three Drivers: 1) the desire to increase processing efficiency; 2) the desire to reduce product unit costs; and 3) the desire to reduce waste disposal costs.

Motivated by these drivers, company officials are seeking a solution that will improve the yield of their potato peeling machine . This is their Capability Gap: A peeling machine that is more efficient than existing technology.

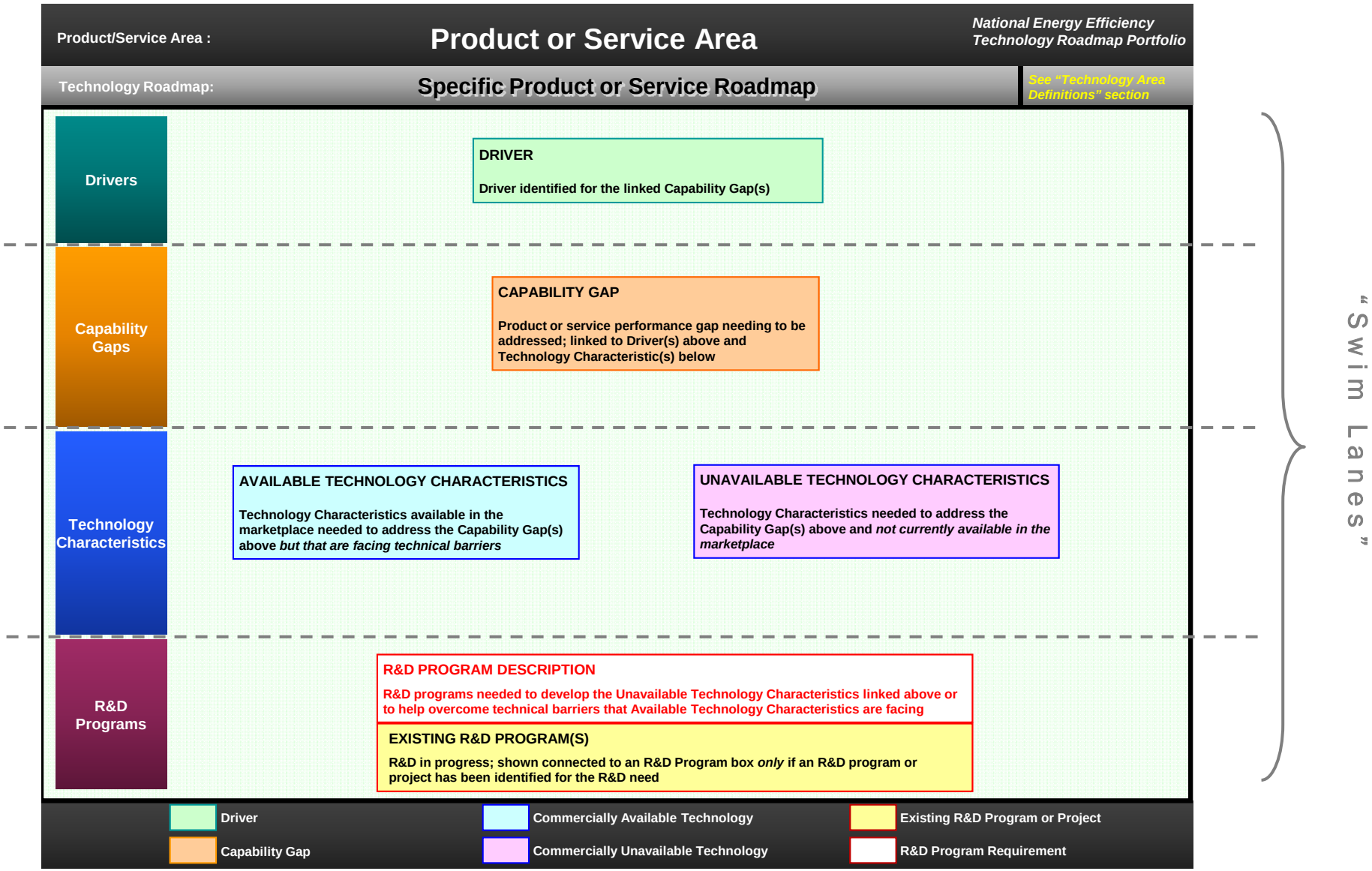
Company officials take their request to their engineering team and ask them to develop a solution that will overcome the capability gap and, thereby, meet the three drivers. The engineering team applies their technical expertise to suggest that if they were to reduce the thickness of the peeler cutting blade they would be able to meet the requirements and overcome the capability gap. Thus the engineers have established a Technology Characteristic.

The engineers' next step is to commence an R&D Program in which they investigate the kinds of metal they could use to create thinner blades and then test these blades.

The diagram to the right illustrates this example:



Roadmap Portfolio Key



R&D Program Summaries Key

R&D Program Title. Brief summary of R&D program needed to develop the associated Unavailable Technology Characteristics or to help overcome technical barriers that Available Technology Characteristics are facing.

Existing research: Institution(s) listed where R&D program(s) are ongoing.

- Brief descriptive summaries of each institution's R&D program that may include, where applicable, hyperlinks to web pages and/or reference to further program details in Appendix B of the *National Energy Efficiency Technology Roadmap Portfolio*.

Key research questions:

1. One or more research questions that subject matter experts have identified as among the key questions and topic areas to pursue within the R&D program or project; numbers provided for identification only and do not imply prioritization.

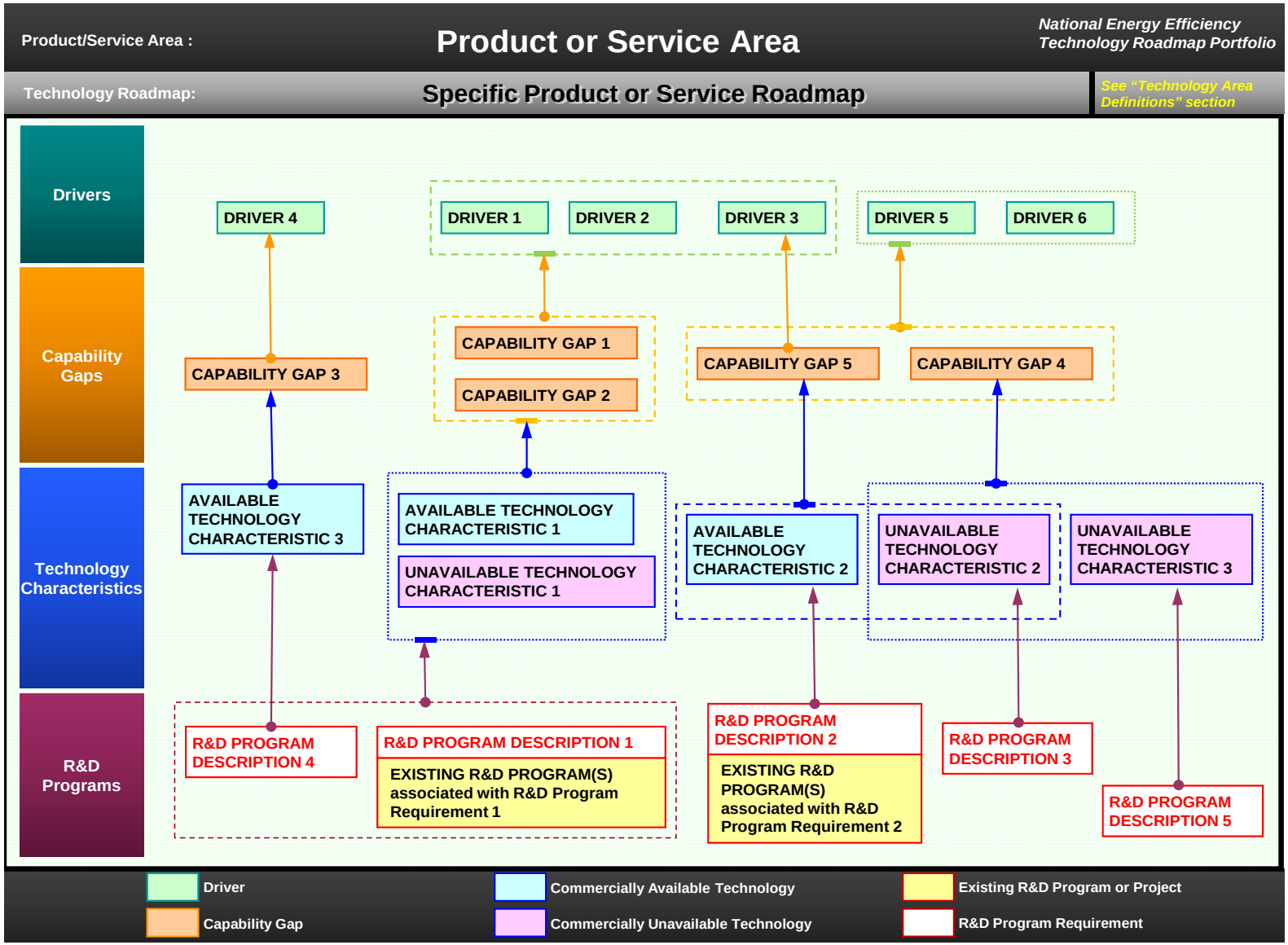
R&D Program Title. Brief summary of R&D program needed to develop the associated Unavailable Technology Characteristics or to help overcome technical barriers that Available Technology Characteristics are facing.

Existing research: None identified. *[R&D program titles that do not have an associated yellow box indicating "Existing R&D Program or Project," by definition, are not underway.]*

Key research questions:

1. One or more research questions that subject matter experts have identified as among the key questions and topic areas to pursue within the R&D program or project; numbers provided for identification only and do not imply prioritization.

How to Interpret Roadmap Portfolio Pages



The diagram above represents a typical Roadmap Portfolio page. The most straightforward way to interpret portfolio pages is from the R&D Programs "swim lane" at the bottom up through the Technology Characteristics, Capability Gaps, and Drivers swim lanes.

	Arrows connect individual or groups of boxes in swim lanes to identify critical connections between them.
	Dotted and dashed lines indicate that two or more elements in a swim lane are associated and linked either to another element (or group of elements) in the swim lane above and/or below.
	Short, thick solid lines indicate that the arrow is connecting to the dotted or dashed line surrounding two or more boxes.

Thus, in the diagram on the preceding page, the red arrow connects R&D Program Description 4 (at bottom left) to Available Technology Characteristic 3; the blue arrow connects Available Technology Characteristic 3 to Capability Gap 3; and the orange arrow connects Capability Gap 3 to Driver 4. This means that R&D Program Description 4 helps meet Driver 4. Expressed in another way, meeting the requirements of Driver 4 is a rationale for engaging in R&D Program Description 4.

For purposes of illustration some of the other associations to be drawn from the diagram above are explained below. The following abbreviations are used in the examples:

- R&D = R&D Program Description
- ATC = Available Technology Characteristic
- UTC = Unavailable Technology Characteristic
- CG = Capability Gap
- D = Driver

R&D 1 and R&D 4 linked to D 1, D 2, and D 3

R&D 1 and R&D 4 are associated by the surrounding dashed box because they both contribute directly to UTC 1 and ATC 1. This is shown by the red arrow from R&D 1 and R&D 4 to the dotted blue box surrounding UTC 1 and ATC 1.

Both of these technology characteristics, in turn, are associated with CG 1 and CG 2, and both of these capability gaps are linked to D 1, D 2, and D 3.

R&D 3 linked to D 3, D 5, and D 6

R&D 3 is linked to UTC 2, as the red arrow indicates, but *not* to ATC 2 or UTC 3 because the red arrow links directly to the UTC 2 box and not the blue dashed or dotted lines.

UTC 2 is linked to both CG 4 and CG 5 in the following ways: first, the blue dotted box associates both UTC 2 and UTC 3 and these together are linked to CG 4 by a blue arrow; next, the blue dashed box associates both UTC 2 and ATC 2 and these are linked by a blue arrow to CG 5.

CG 4 and CG 5 are associated with one another as indicated by the dashed orange box surrounding them and an orange arrow links both capability gaps to D 5 and D 6.

Though CG 4 and CG 5 are associated in their linkage to D 5 and D 6, CG 5 independently is linked to D 3, as the orange arrow connecting CG 5 and D 3 indicates.

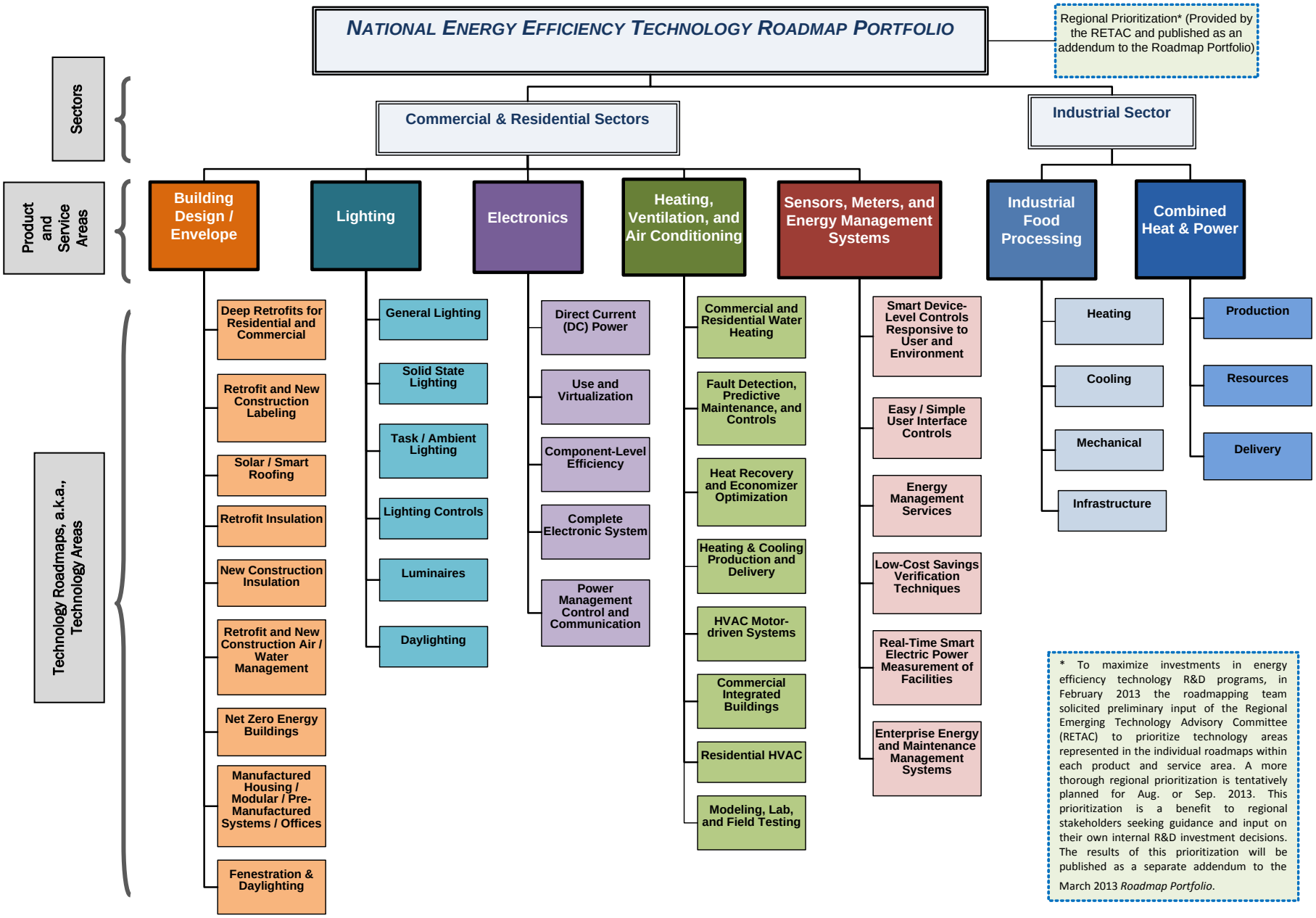
R&D 2 linked to D 3

A red arrow links R&D 2 with ATC 2.

ATC 2 and UTC 2 are associated as is shown by the blue dashed box surrounding them. The blue arrow from this box connects to CG 5.

An orange arrow links CG 5 to D 3 but *not* to D 1 and D 2. These three drivers are associated with one another but only in terms of their linkage to CG 1 and CG 2, not in terms of their linkage to CG 5.

Roadmap Portfolio Organizational Chart



Technology Area Definitions

Building Design / Envelope

Deep Retrofits for Residential and Commercial Buildings

A whole-building analysis and construction process that uses an integrative approach (rather than focusing on isolated energy systems) to achieve much larger energy savings than conventional energy retrofits.

Retrofit and New Construction Labeling

A program that provides the general public, building owners and tenants, potential owners and tenants, and building operations and maintenance staff an overview of the energy performance of a building so that they can make more informed decisions about purchasing, renting, leasing, and upgrading buildings.

Solar/Smart Roofing

Integrating solar thermal and solar electric (building-integrated photovoltaic) technologies into roofing materials.

Retrofit Insulation

Techniques and materials for adding insulation to the building envelope of an existing building. Also includes using infrared scanning technology to observe and analyze variations in heat flows in and through the envelope of a building to improve design and construction and minimize heating and cooling losses from air leaks and inadequate insulation.

New Construction Insulation

Roof, wall, and floor insulation in new construction.

Retrofit and New Construction Air / Water Management

Minimizing (and ideally eliminating) air leakage and water infiltration through penetrations and gaps in the building envelope for wiring, plumbing, ductwork, etc.

Net Zero Energy Buildings

Technologies and techniques used to design and construct buildings with greatly reduced needs for energy through very high efficiency such that the balance of energy needs are supplied with renewable technologies on-site.

Manufactured Housing / Modular / Pre-Manufactured Systems / Offices

Technologies and techniques used in a factory to produce pre-built homes delivered to a site in one or more pieces that, once assembled, provide a home ready for occupancy.

Fenestration & Daylighting

Fenestration, shades, and daylighting products and services that conserve energy. Includes: increasing the energy efficiency of windows in existing and new buildings; windows, translucent walls, and mirrored tubes to bring daylight more deeply into occupied spaces; and using operable insulating materials (such as window quilts and roman shades) to cover windows to reduce heating and cooling losses and block light.

Lighting

General Lighting

Technologies and strategies to optimize the use of lighting fixtures, components, and controls for general illumination (rather than decorative, traffic, signs, etc.).

Solid State Lighting

More affordable, efficacious, and reliable light emitting diode (LED) lighting system, using technologies and techniques that take full advantage of LED's characteristics, such as directionality, long life, and controllability while mitigating concerns such as heat management, lumen maintenance, color-shift, and component failure.

Task/Ambient Lighting

Products and systems design to minimize total lighting energy use by minimizing ambient lighting and providing effective and efficient task lighting.

Lighting Controls

Technologies and design approaches to improve the effectiveness and usability of lighting controls to minimize energy use while maintain good lighting quality.

Luminaires

Materials and designs to improve the optical efficiency of luminaires, which may consist of a body, ballasts, reflector, and lens.

Daylighting

Technologies and strategies to maximize the use of daylight and minimize the need for electric lighting while maintaining good quality lighting that promotes health and productivity.

Electronics

Direct Current (DC) Power Source

Providing direct current (DC) power in buildings to operate equipment while eliminating energy losses of transformers, improving motor speed control, and integrating more directly with photovoltaic systems.

Use and Virtualization

Techniques for using consumer electronics and computers to minimize energy use without sacrificing functionality, such as through integration and server virtualization.

Component-Level Efficiency

Producing components for consumer electronics, such as power supplies and chips, that are much more energy efficient than those in common use.

Complete Electronic System

Using integrated design to produce consumer electronics and computer servers than are significantly more energy efficient than those commonly in use while not sacrificing product functionality.

Power Management Control and Communication

Reducing energy use through “sleep modes” that minimize standby losses of consumer electronics while not interfering with the user experience. Also includes automated technologies to reduce energy use of plug loads according to occupants’ needs, preferably convenient to users and affordable to building owners.

Heating, Ventilation, and Air Conditioning (HVAC)

Commercial and Residential Water Heating

Technologies to heat water for residential and commercial applications.

Fault Detection, Predictive Maintenance, and Controls

Automated notification of changes in components, such as dampers, amp draw, filters, etc., that will allow maintenance to be addressed sooner, thereby improving the system efficiency and minimize premature and major equipment failures.

Heat Recovery and Economizer Optimization

Maximizing use of non-mechanical cooling with outside air and of heat from cooled spaces to reduce energy use.

Heating & Cooling Production and Delivery

Producing and delivering heating and cooling through large heating, ventilation, and air conditioning (HVAC) systems.

HVAC Motor-driven Systems

Energy efficient motors and drives, primarily adjustable speed drives, used in heating and cooling equipment, along their motor control systems.

Commercial Integrated Systems

Products and services developed from a holistic systems perspective to provide for complementary and integrated heating, ventilation, and air conditioning tailored to the requirements of commercial, multi-family residential, and high-rise office buildings.

Residential HVAC

Products and services developed from a holistic systems perspective to provide for complementary and integrated heating, ventilation, and air conditioning tailored to the requirements of residential buildings.

Modeling, Lab and Field Testing

Using a combination of computer modeling software and lab or field testing to predict the performance of heating and cooling systems in a variety of applications.

Sensors, Meters, and Energy Management Systems

Smart Device-level Controls Responsive to User and Environment

Automated energy management systems that responds effectively to input from users and the environmental conditions.

Easy/Simple User Interface Controls

An energy management system that is easy to use and understand.

Energy Management Services

Home energy management systems integrated with a service to help consumers understand and reduce their energy use.

Low-cost Savings Verification Techniques

Devices and software used to verify energy savings from implementation of measures without the significant time and expense of a conventional measurement and verification study.

Real-time Smart Electric Power Measurement of Facilities

Devices and systems to gather data on building operation schedules as well as energy use and demand in real time so users or an energy management system can respond effectively.

Enterprise Energy and Maintenance Management Systems

Energy management systems for large organizations with multiple buildings, such as a corporate or university campus.

Industrial Food Processing

Heating

Technologies used for heating food and industrial food processing equipment.

Cooling

Technologies used for cooling food and industrial food processing equipment.

Mechanical

Various mechanical and technical systems used within the industrial food processing facility outside of the realm of heating and cooling technologies, such as raw material storage, transportation, and equipment operation.

Infrastructure

Technical infrastructure to support industrial food processing operations such as lighting, HVAC systems, energy management systems, water treatment, data management, and others.

Combined Heat and Power

Production

Technologies used to generate heat and power, such as fuel cells, turbines, generators, and heat recovery systems.

Resources

Identifying, sourcing, delivering, and storing fuel used within combined heat and power systems.

Delivery

Storing, moving, and optimizing both heat and energy generated from combined heat and power systems.

Building Design / Envelope Roadmaps

This section contains the following roadmaps:

- Deep Retrofits for Residential and Commercial
- Retrofit and New Construction Labeling
- Solar/Smart Roofing
- Retrofit Insulation
- New Construction Insulation
- Retrofit and New Construction Air / Water Management
- Zero Net Energy Buildings
- Manufactured Housing / Modular / Pre Manufactured Systems / Offices
- Fenestration & Daylighting

Other relevant sources

The list below is intended to be broadly representative rather than exhaustive and will be updated as new information becomes available.

Oregon Built Environment & Sustainable Technologies Center (Oregon BEST), "Deep Retrofits Research Agenda," Nov. 2012, http://oregonbest.org/sites/default/files/consortium/adf2012-09_deepretrofitsresearchagenda_lowresv2.pdf.

Oregon Built Environment & Sustainable Technologies Center (Oregon BEST), "Living Building Challenge Materials Research Agenda," Jan. 2013, http://oregonbest.org/sites/default/files/consortium/adf2012-11_lbcmaterialsresearchagenda.pdf.

U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, *Buildings R&D Breakthroughs: Technologies and Products Supported by the Building Technologies Program*, April 2012, http://apps1.eere.energy.gov/buildings/publications/pdfs/corporate/rd_ breakthroughs.pdf.

U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, *Summary of Gaps and Barriers for Implementing Residential Building Energy Efficiency Strategies*, Aug. 2012, http://apps1.eere.energy.gov/buildings/publications/pdfs/building_america/49162.pdf.

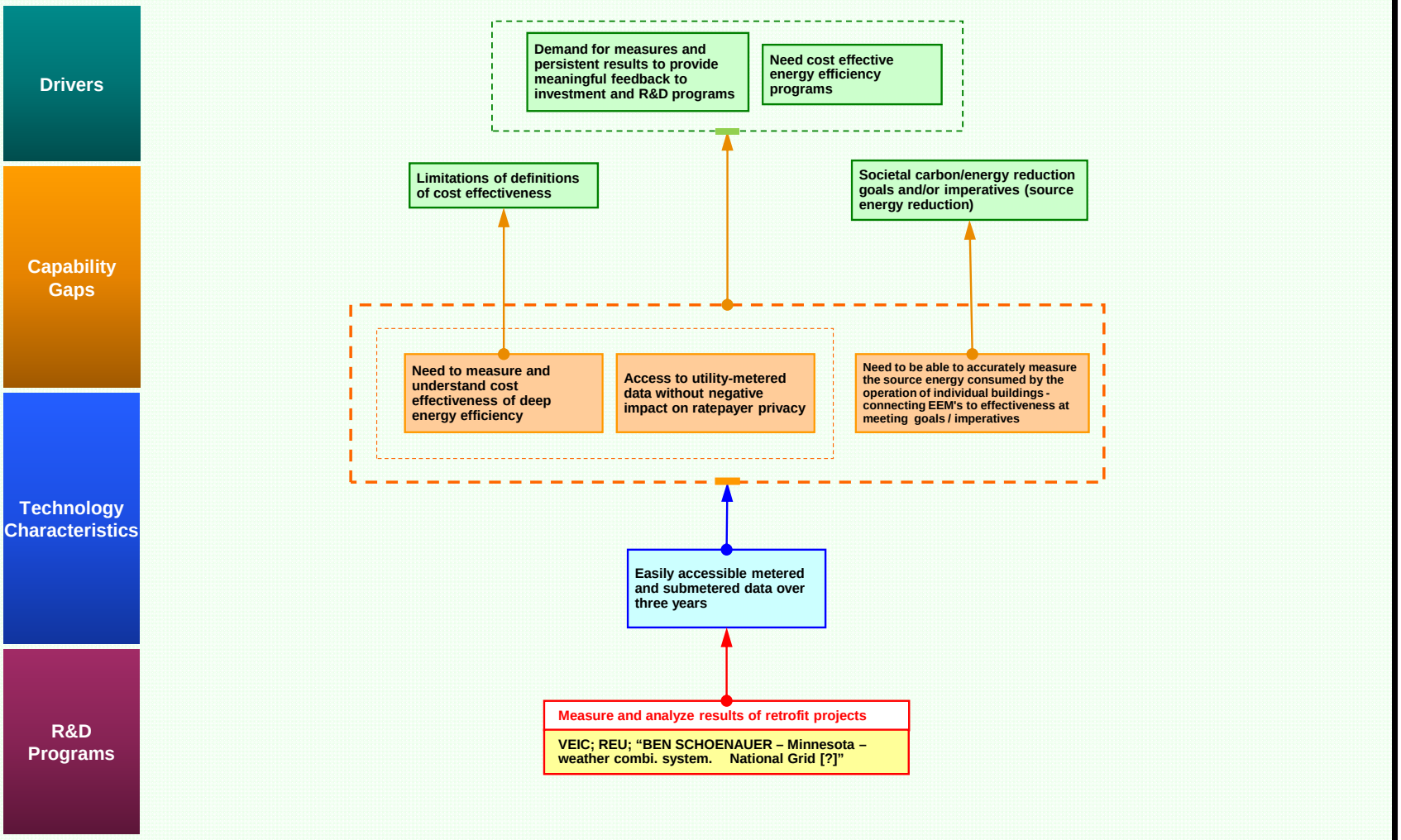
U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, Windows and opaque building envelope roadmaps (as of November 2012, these roadmaps were soon to be published at http://www.eereblogs.energy.gov/buildingenvelope/).

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Deep Retrofits for Residential & Commercial (1 of 5)**

See "Technology Area Definitions" section



Driver | Commercially Available Technology | Existing R&D Program or Project

Capability Gap | Commercially Unavailable Technology | R&D Program Requirement

R&D Program Summaries

Measure and analyze results of retrofit projects. Measure, record, summarize, and analyze the actual change in energy consumption as a result of the energy retrofit. Need three years of measured results.

Existing research: Subject matter experts in September 2012 indicated that ongoing research was being done through the Vermont Energy Investment Corporation (VEIC), the Redding Electric Utility's (REU) Home Performance Program, and through an as-yet unidentified program identified as "BEN SCHOENAUER – Minnesota – weather combi. system."

- VEIC: http://www.veic.org/index.aspx.
- REU (Redding, California) Home Performance Program: http://www2.reupower.com/rebate_hpp.asp.

Key research questions:

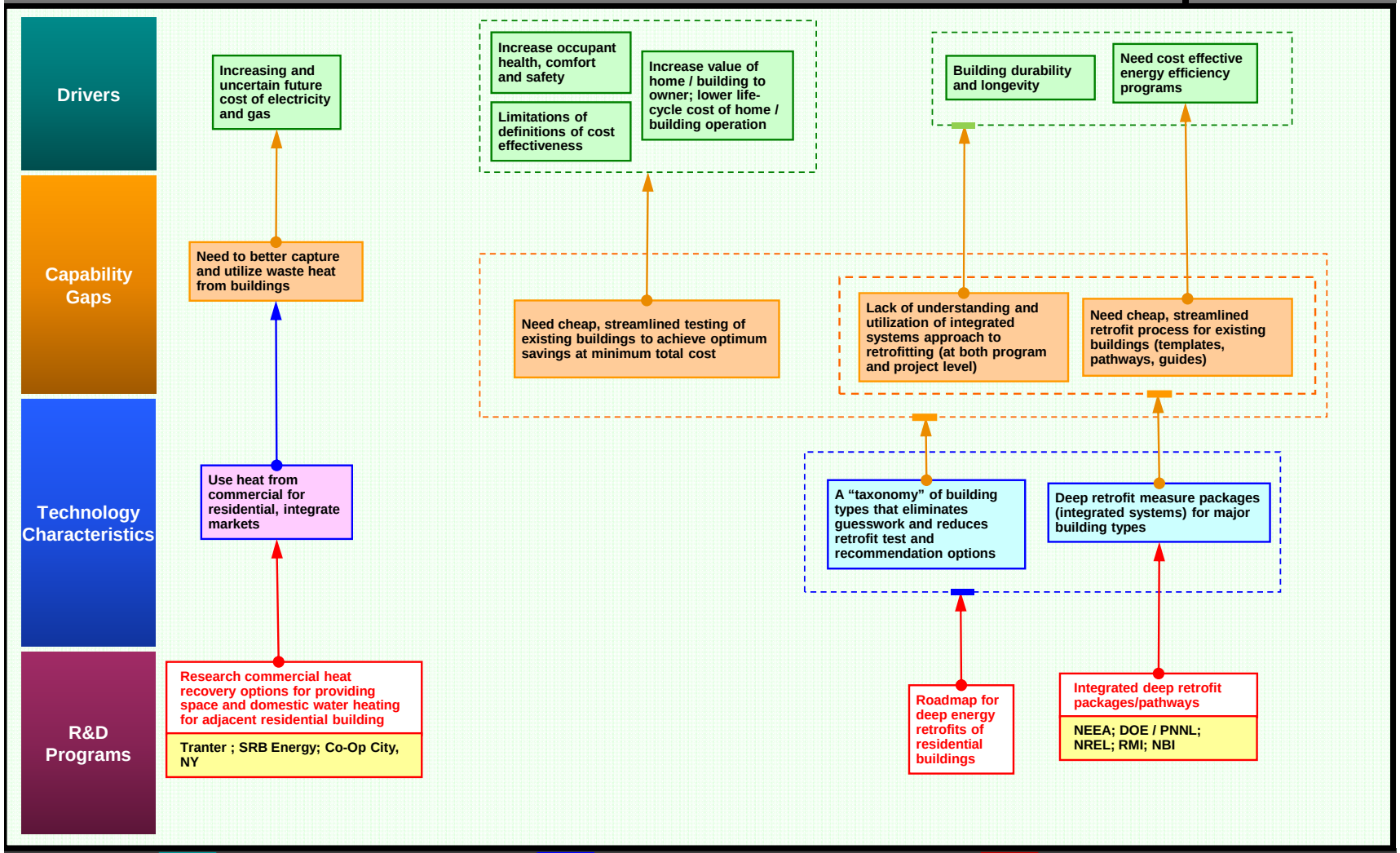
1. How much and what type of metering/submetering data is required to ensure meaningful conclusions?
2. How much building characterization (level of detail, e.g. location, size, number of homes, age, upper levels) is necessary to ensure meaningful conclusions of program effectiveness?
3. What has been the effect of retrofit on comfort, durability and safety, and indoor air quality (IAQ)?
4. Did the retrofit (each project) save energy? If so
    a. How much, and
    b. For how long?
5. What were the unanticipated benefits and/or negative consequences?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Deep Retrofits for Residential & Commercial (2 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Integrated deep retrofit packages/pathways. Streamline, pre-analyzed packages of measures that are based on integrated design (and integrated systems) for different building types. Includes: a) a process to custom fit, b) specific measures.

Existing research: Subject matter experts in September 2012 indicated that ongoing research was being done by the Northwest Energy Efficiency Alliance (NEEA); the U.S. Department of Energy (DOE), Pacific Northwest National Laboratory (PNNL), and the National Renewable Energy Laboratory (NREL)'s collaboratively-produced Advanced Energy Retrofit Guides (AERGs); at the Rocky Mountain Institute (RMI); and through a collaboration among the New Building Institute (NBI) and the National Trust for Historic Preservation's (NTHP) Green Lab.

- NEEA's existing building renewal integrated measure package (IMP) development: http://neea.org/initiatives/commercial/existing-building-renewal.
- AERGs: http://www1.eere.energy.gov/buildings/commercial/aerg.html.
- RMI's Retrofit Depot: http://www.rmi.org/retrofit_depot.
- NBI (http://newbuildings.org/) and NTHP Green Lab (http://www.preservationnation.org/information-center/sustainable-communities/sustainability/green-lab/); see http://www.preservationnation.org/information-center/sustainable-communities/sustainability/green-lab/getting-to-50.html.

Key research questions:

1. What building types are most suitable for "packages"?
2. What types are not covered by current R&D?
3. What measures, groups of measures are cost-effective?
4. How can pre-analyzed measures be "fit" to each unique existing building?
5. What tools are needed to facilitate the process?
6. What evidence (measure performance) exists for current packages?

Roadmap for deep energy retrofits of residential buildings. Characterize evolving landscape and process imperatives of successful large home remodeling projects to provide roadmap for successful and persistent deep energy retrofit programs and projects. Provide demonstration project(s) to show that the roadmap is accurate, identifying how different disciplines interact.

Existing research: None identified.

Key research questions:

1. What are the key decision points at which deep energy retrofit measures can be implemented?
2. Who are the decision makers and decision influencers at those moments and what are their motivations?
3. What are speed bumps and pot holes at each decision point in the process and how can they be navigated?
4. What are the assets and liabilities of the industry/energy infrastructure with respect to deep energy retrofits?
5. What is the most effective way to use/ distribute roadmap to increase the number of quality of deep energy retrofit?

Continued . . .

Research commercial heat recovery options for providing space and domestic water heating for adjacent residential buildings. With co-located commercial and residential buildings, commercial waste heat recovery can be more cost effective by utilizing it for adjacent residential use.

Existing research: As of January 2011, E Source reported that factors such as distribution losses and the need for customized engineering on both the commercial and residential side may pose obstacles to making this a cost-effective efficiency strategy and, while this is an interesting approach, they were not aware of any current research being done in this area.

Subject matter experts reported in September 2012 that leaders in district heating include European companies like Tranter and SRB Energy; notable U.S. projects include Cooperative ("Co-op") City in NY.

- Tranter's compact plate heat exchangers: http://www.tranter.com/Pages/Home.aspx.
- SRB Energy's solar thermal collector featuring ultra high vacuum technology: http://www.srbenergy.com.
- Co-Op City, NY: http://www.riverbaycorp.com/newrb/community.htm.

Key research questions:

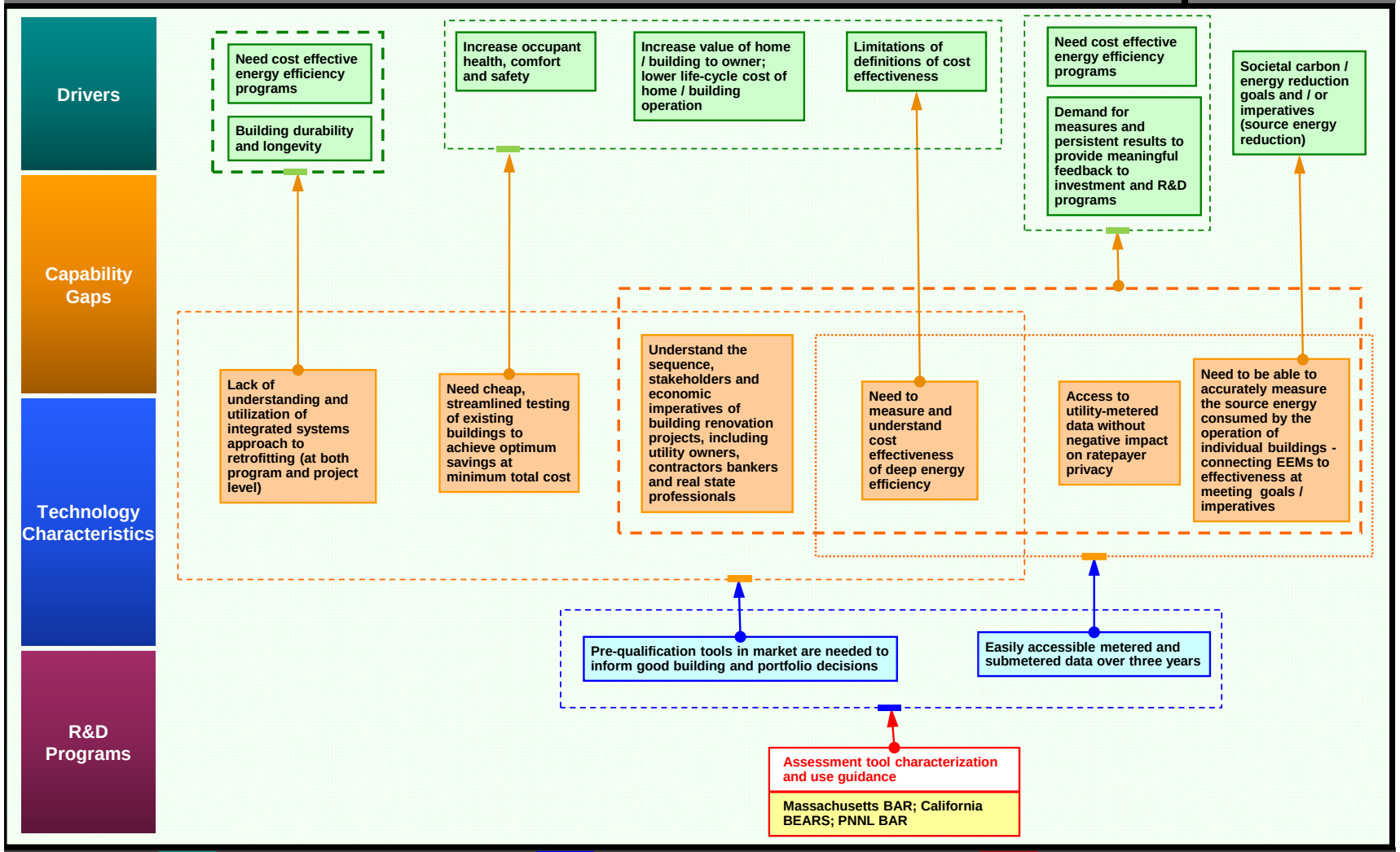
1. Measuring/mapping thermal characteristics or profiles of existing building stock. Temperature and through-put and time-profile of waste heat available.
2. What is the feasibility of capturing commercial waste heat for different configuration of com/res mixed use building areas? How do we define major categories of mixed-use building configurations?
3. Identify idea scale(s) for thermal sharing? (Single building, district, campus, etc).
4. How would heat exchanger technologies/topologies need to evolve/adapt for more cost-effective recovery and re-use of waste heat in com/res mixed building configurations?
5. How can thermal storage technologies be best played to capture energy from waste heat?
6. Characterize major types of mixed use building configurations, including approximate market share of each configuration.
7. Characterize thermal characteristics of different types of commercial waste heat: Temperature ("quality" of waste heat), volumetric flow ("quality" of waste heat), and temporal profile (schedule of waste heat).
8. Identify technological gaps - e.g. technological gaps to building configurations and waste heat characteristics.
9. Map technological gaps to building configurations and waste heat characteristics.
10. Identify thermal storage applications that would enable (or make feasible) waste capture and re-use.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Deep Retrofits for Residential & Commercial (3 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Assessment tool characterization and use guidance. Conduct market characterization of various tools for low-cost/low-touch prequalification methodologies, such as the FirstFuel load signature disaggregation tool (http://www.firstfuel.com/home/how_it_works); identify tools that perform like this and also innovative modeling prediction tools to help portfolio managers know what they are getting and evaluate the pros and cons.

Existing research: Subject matter experts reported in September 2012 that existing tools include Massachusetts Building Asset Rating (BAR) tool, the Commercial Building Energy Asset Rating System (BEARS) in California, and the Pacific Northwest National Laboratory (PNNL) Building Energy Asset Rating (BEAR) program, among others.

- Massachusetts BAR tool:http://www.mass.gov/eea/energy-utilities-clean-tech/energy-efficiency/building-labeling/building-rating-and-labeling-commercial-buildings.html.
- California BEARS: See Eliot Crowe, *et al.*, "California's Commercial Building Energy Asset Rating System (BEARS): Technical Approach and Design Considerations," 2012 ACEEE Summer Study on Energy Efficiency in Buildings, http://www.aceee.org/files/proceedings/2012/data/papers/0193-000104.pdf.
- PNNL BEAR program: M.J. McCabe and N. Wang, "Commercial Building Energy Asset Rating Program: Market Research," April 2012, http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21310.pdf.

Key research questions:

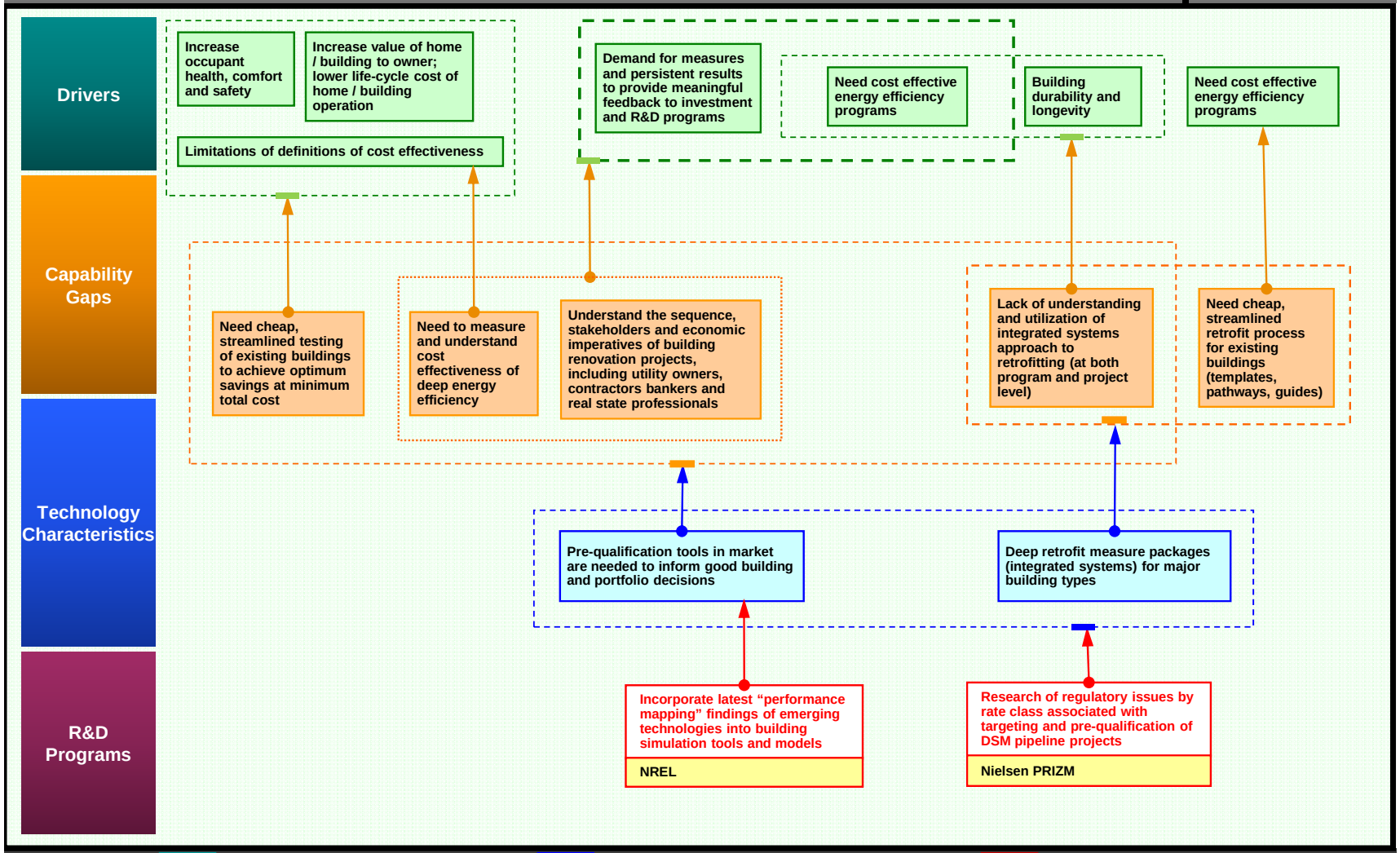
1. ID tools that currently exist: e.g. first fuel, first view, etc.
2. Evaluate tools that currently exist.
3. Report pros/cons of various tool and their methodologies.
4. ID gaps for needed tools.
5. Evaluate how these tools affect retrofit building operation programs.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Deep Retrofits for Residential & Commercial (4 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Incorporate latest "performance mapping" findings of emerging technologies into building simulation tools and models. Research is underway at many organizations to map the performance of energy technologies at various ambient condition or operating profiles (i.e. load profiles). However, this information is not necessarily captured and incorporated into building energy simulation tools and models that are employed to predict energy savings of multiple interactive measures. The industry would benefit from a systematic approach to capture new performance results from lab/field tests and incorporate them into building simulation models.

Existing research: Subject matter experts reported in September 2012 that research in this area is ongoing at the National Renewable Energy Laboratory (NREL).

- NREL's Technology Performance Exchange: http://www.nrel.gov/docs/fy13osti/56457.pdf.

Key research questions:

1. What ongoing research is being done to map the performance of different categories of emerging technologies to various ambient/climate conditions, loading profiles, and applications? Who is doing what?
2. To what extent are leading building simulation models being updated to capture these new leanings?
3. Is there a standard protocol for data inputs for these leading building energy simulation models that could drive/guide research design of energy technology performance mapping?
4. What entities are best positioned to take on the task of doing these tracking and monitoring to ensure technology transfer of energy technology testing results into building simulation models?

Research of regulatory issues by rate class associated with targeting and pre-qualification of DSM pipeline projects. (Summary not yet provided.)

Existing research: Subject matter experts reported in September 2012 that many utilities—including Pacific Gas & Electric (PG&E), National Grid, and Avista—are using the Nielson PRIZM market segmentation tool and other tools to target and pre-qualify customers.

- Nielsen PRIZM: http://www.claritas.com/MyBestSegments/Default.jsp.

Key research questions:

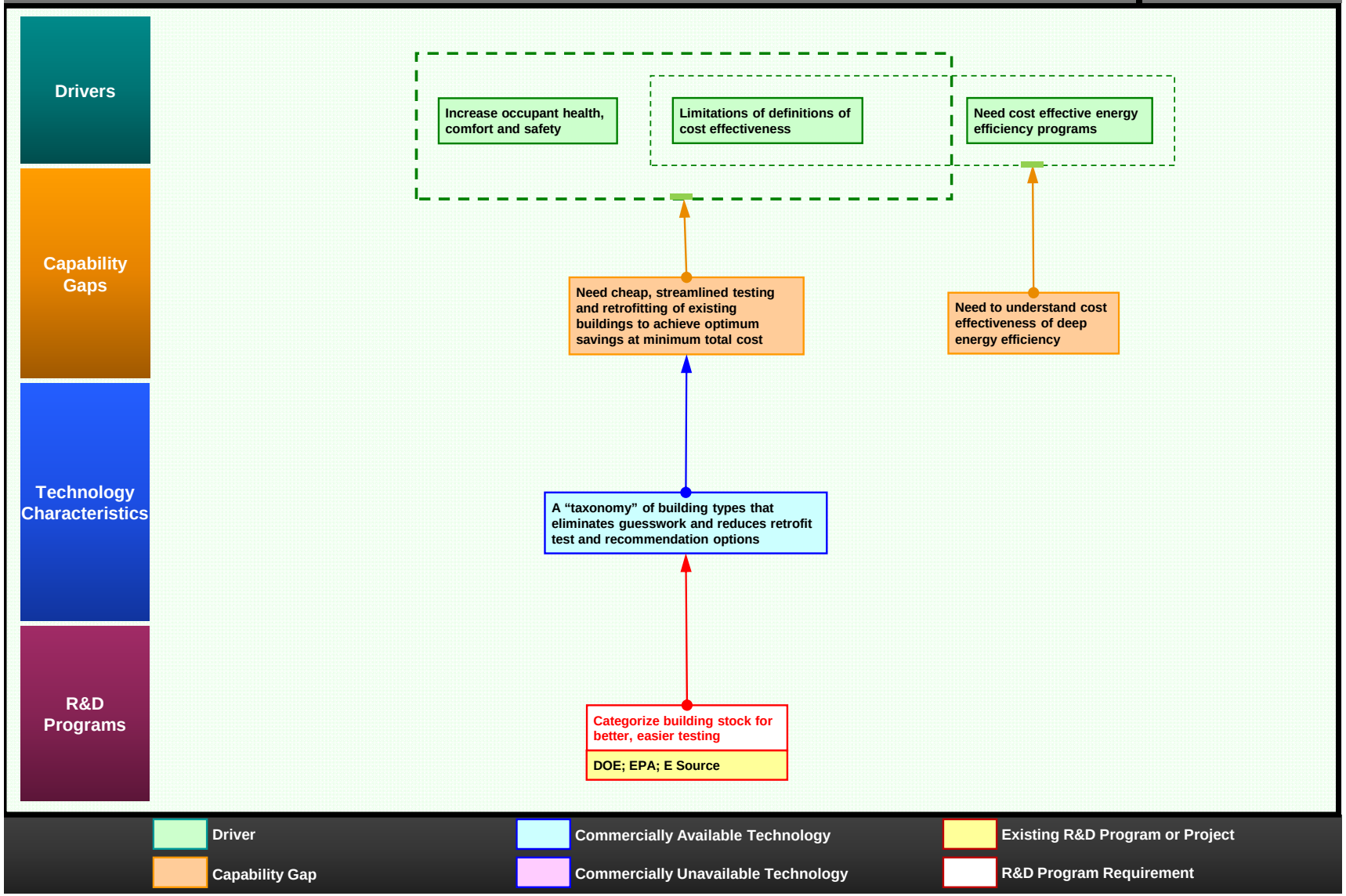
1. If the saving (KWh/BTUs) are the primary metric and targeting buildings for demand-side management (DSM) pipeline maximizes that metric, will equity issues create challenges? (example: If I have a service territory with 14,000 buildings and with targeted benchmarking, I know 400 exceed their benchmarking, can I target those 400, or must I make programs open to all prospective participant and why?)

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Deep Retrofits for Residential & Commercial (5 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Categorize building stock for better, easier testing. If a wide range of building stock is sorted into categories, energy assessments can be performed more expeditiously.

Existing research: There are four regularly-updated tools available for this purpose, one tool in beta testing, and one longstanding data source that is no longer kept current.

- The U.S. Environmental Protection Agency (EPA) has designed an ENERGY STAR portfolio manager tool to help facility managers track and benchmark energy and water consumption across an entire portfolio of buildings (http://www.energystar.gov/index.cfm?c=evaluate_performance.bus_portfoliomanager)
- The U.S. Department of Energy's (DOE) Residential Energy Consumption Survey characterizes U.S. homes through such data as structural features, fuels used, heating and cooling equipment, appliances, and energy usage patterns (http://www.eia.doe.gov/emeu/recs/).
- E Source's EnFocus system integrates geographic information system (GIS) data with utility billing records and could be used to categorize building stock and identify individual buildings (http://www.esource.com/esource/preview_list/27113?highlight=allsubs&plain=no).
- E Source also provides clients a Residential Energy Use Study that they update annually with comparative data (http://www.esource.com/Residential_Energy-Use_2011).
- Specifically for lighting, the DOE's Commercial Lighting Solutions website provides facility-specific information on best practices and allows users to compare and contrast different lighting strategies easily. As of January 2012, this tool is available and in beta testing (https://www.lightingsolutions.energy.gov/comlighting/login.htm).
- The DOE and the EPA collaborated on a national Commercial Buildings Energy Consumption Survey (CBECS) from 1979 through fiscal year 2010 (September 2010). This survey collected information on the stock of U.S. commercial buildings, their energy-related building characteristics, and their energy consumption and expenditures. Survey data is no longer kept current because Congress de-funded the project beginning fiscal year 2011 (http://www.eia.doe.gov/emeu/cbecs/).

Key research questions:

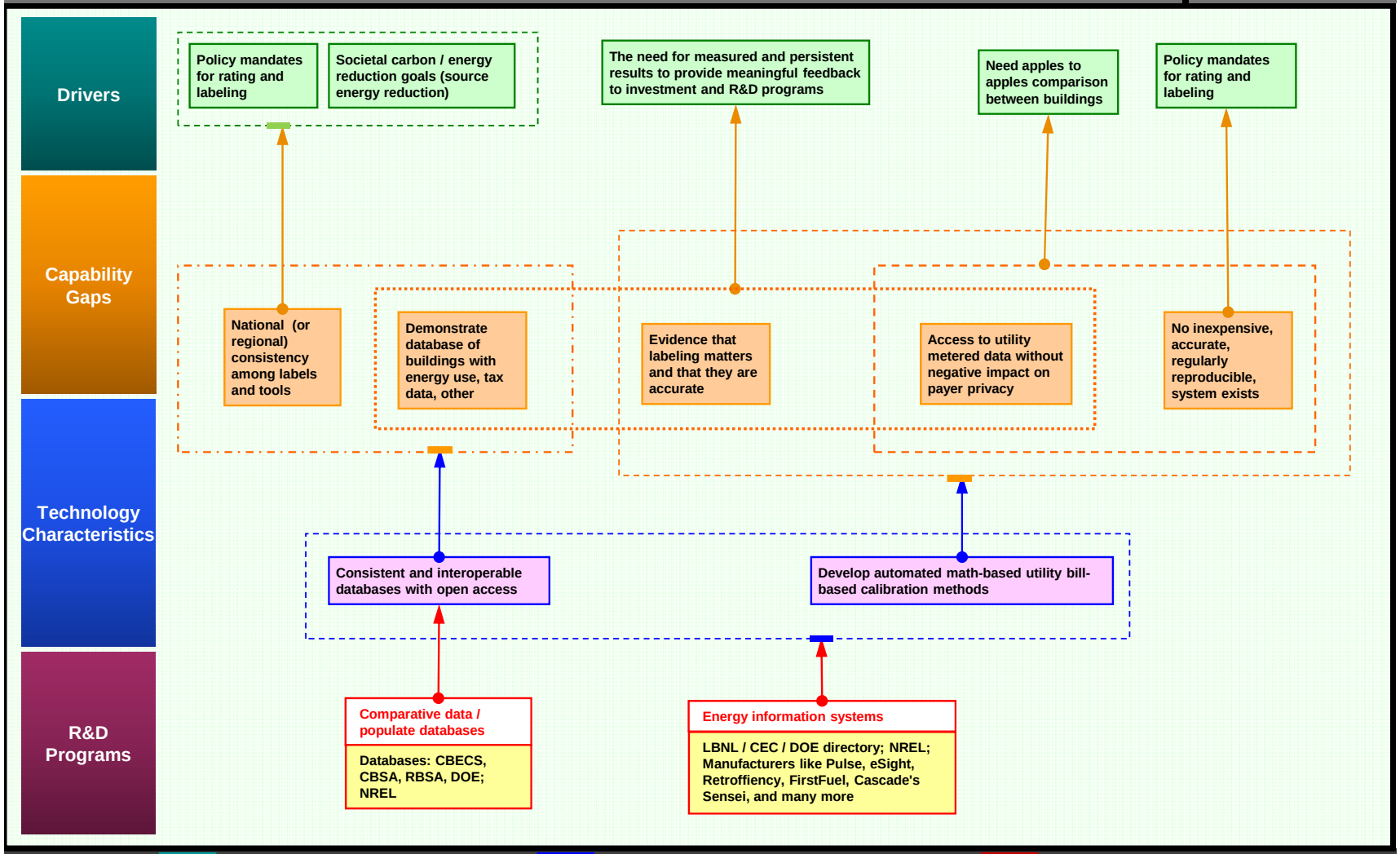
1. Questions not yet specified

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Labeling (1 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Comparative data/populate databases. Significantly expand data availability for comparisons for benchmarking, model calibration, financing. Scope: supplement existing data collection, add new data projects.

Existing research: Subject matter experts reported in September 2012 of the potential of expanding existing databases such as the Commercial Buildings Energy Consumption Survey (CBECS), Commercial Building Stock Assessment (CBSA), Residential Building Stock Assessment (RBSA), and Department of Energy (DOE) databases. They also referenced the National Renewable Energy Laboratory's (NREL) work in this area.

- CBECS: http://www.eia.gov/consumption/commercial/.
- CBSA: http://neea.org/resource-center/regional-data-resources/commercial-building-stock-assessment.
- RBSA: http://neea.org/resource-center/regional-data-resources/residential-building-stock-assessment.
- DOE: http://www1.eere.energy.gov/buildings/commercial/ref_buildings.html.
- NREL's Technology Performance Exchange: http://www.nrel.gov/docs/fy13osti/56457.pdf.

Key research questions:

1. What are the characteristics of state of art retrofits?
2. What are the cost, performances, and loads?
3. What components contribute to performance?
4. How can multiple data sources be aggregated?
5. What are the common characteristics?
6. Combine databases from disclosure programs.

Energy information systems. Energy information and systems to collect and make data available to building designers and facility management staff are keys to achieving carbon-neutrality by 2030, which requires buildings, which contribute almost 50 percent of greenhouse gas emissions, to be designed to 50 percent of current average energy use for the building type and region. The establishment of building energy labeling requires sharing building energy performance data to establish performance benchmarks and ratings.

Existing research: Subject matter experts reported in September 2012 that work in this area continues at the Lawrence Berkeley National Laboratory (LBNL), California Energy Commission (CEC), Department of Energy (DOE), and the National Renewable Energy Laboratory (NREL).

- LBNL has been working with the CEC and the DOE for fifteen years to test and track emerging and in-use energy information systems. This directory can be found at http://eis.lbl.gov/, and more information can be found in Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

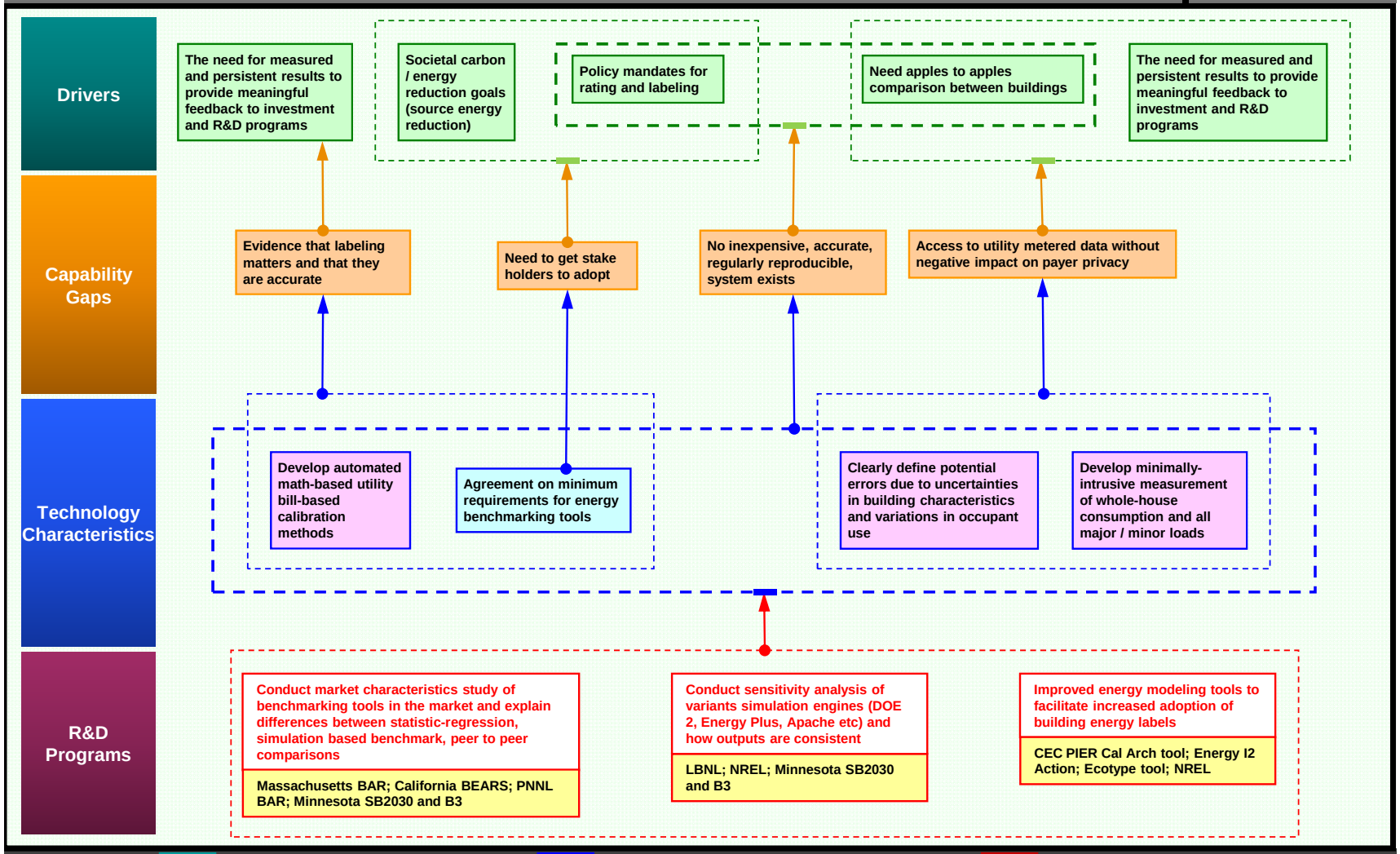
1. Identify the tools currently available in the market?
2. Analyze and evaluate energy information systems (EIS), energy management systems (EMS), building automation systems (BAS), enterprise systems, their features, methodologies and capabilities.
3. Include analysis of how tools feed output into labels for buildings and portfolio of buildings?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Labeling (2 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Improved energy modeling tools to facilitate increased adoption of building energy labels. The broad adoption of building energy labels requires better energy modeling tools.

Existing research: Stakeholders recommended the California Energy Commission's Public Interest Energy Research (PIER) program Cal Arch tool; Energy I2 Action; and Ecotype. They also referred to the National Renewable Energy Laboratory's (NREL) work in this area.

- CEC PIER (http://www.energy.ca.gov/research/) sponsored the development of Cal-Arch, a web-based tool for energy use benchmarking (http://buildings.lbl.gov/hpcbs/Element_2/02_E2_P2_1_1.html). Cal-Arch uses data from both the U.S. Department of Energy's Commercial Buildings Energy Consumption Survey (CBECS) and California's Commercial End Use Survey (CEUS) (http://poet.lbl.gov/cal-arch/ceus.html). The CBECS is no longer funded as of Fiscal Year 2012, and the CEUS was last conducted in 2008. The most recent version of the tool (2008) is available at http://poet.lbl.gov/cal-arch/.
- The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE, http://www.eere.energy.gov/) maintains a periodically-updated Building Energy Software Tools Directory. As of December 2011, this directory contained 405 software tools used to track and evaluate energy efficiency, renewable energy, and sustainability (http://apps1.eere.energy.gov/buildings/tools_directory/).
- As of Feb. 2012, no further information could be found about the Energy I2 Action and Ecotype energy modeling tools or their respective development teams.
- NREL Mobile Audit and PV Assessment Tool (simuwatt): See Appendix B for more information.

Key research questions:

1. Questions not yet specified.

Conduct market characteristics study of benchmarking tools. Evaluate benchmarking tools in the market and explain differences between statistic-regression, simulation based benchmark, and peer to peer comparisons.

Existing research: Subject matter experts reported in September 2012 that existing tools include Massachusetts Building Asset Rating (BAR) tool, the Commercial Building Energy Asset Rating System (BEARS) in California, and the Pacific Northwest National Laboratory (PNNL) Building Energy Asset Rating (BEAR) program, Minnesota Sustainable Building 2030 program (SB2030), and the Minnesota Building Benchmarking and Beyond (B3) guidelines.

- Massachusetts BAR tool:http://www.mass.gov/eea/energy-utilities-clean-tech/energy-efficiency/building-labeling/building-rating-and-labeling-commercial-buildings.html.
- California BEARS: See Eliot Crowe, et al., "California's Commercial Building Energy Asset Rating System (BEARS): Technical Approach and Design Considerations," 2012 ACEEE Summer Study on Energy Efficiency in Buildings, http://www.aceee.org/files/proceedings/2012/data/papers/0193-000104.pdf.
- PNNL BEAR program: M.J. McCabe and N. Wang, "Commercial Building Energy Asset Rating Program: Market Research," April 2012, http://www.pnnl.gov/main/publications/external/technical_reports/PNNL-21310.pdf.
- Minnesota SB 2030: http://www.mn2030.umn.edu/history.html.
- Minnesota B3: http://www.msbg.umn.edu/.

Key research questions:

1. Identify the tools.
2. Identify the methodologies used by the tools.
3. Analyze and describe the pros and cons of methodologies and the consistency of outputs that feed labels.
4. Include implications of consistency and transparency.

Continued . . .

Conduct sensitivity analysis of variants simulation engines. Analyze DOE 2, Energy Plus, Apache, and other simulation engines to determine how outputs are consistent.

Existing research: LBNL, NREL, MN B3, MN SB2030.

- *[Summaries of existing research pending]*

Key research questions:

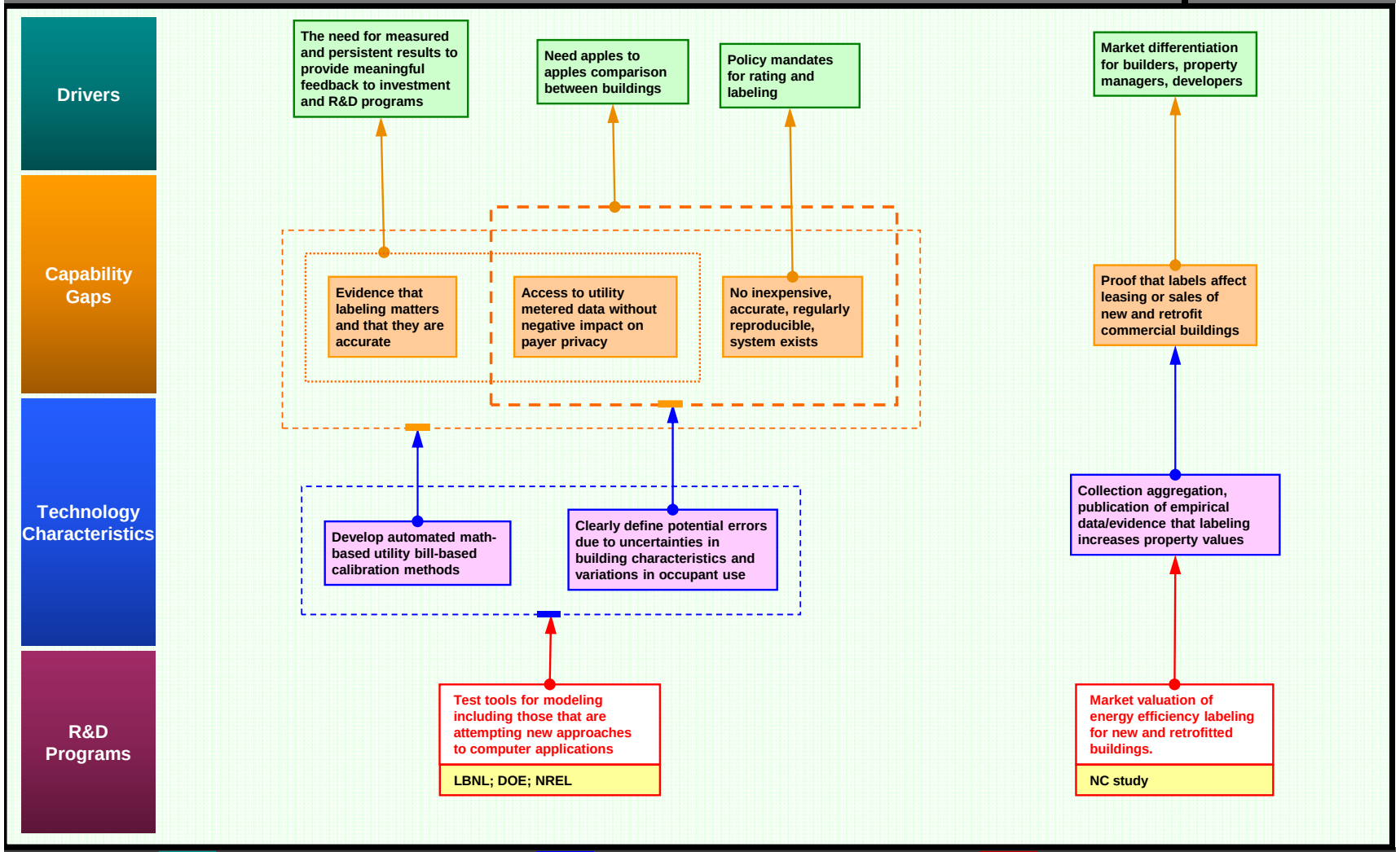
1. Identify the issues that create variability in outcomes that will feed labels.
2. Analyze and evaluate outputs using common building.
3. Analyze the ability of variants tools to use different simulation engines include implications in rating labeling and disclosure policies.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Labeling (3 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Market valuation of energy efficiency labeling for new and retrofitted buildings. RE appraisal valuation of energy efficiency building components to control groups of comparable properties without EE improvement. Also methods to translate this value into RE process to accelerate adoption.

Existing research: Subject matter experts reported in September 2012 referred to "NC study."

- *[Summaries of existing research pending]*

Key research questions:

1. Do EE improvements increase property value of buildings (new and retrofitted existing)?
2. How can RE appraisal process better account for the value of EE?
3. What are non-energy benefits of EE improvements and how they affect property value?
4. How can EE labels document results to increase the market adoption (i.e. appraisal process)?
5. Do labels increase the value of EE improvements?

Test tools for modeling including those that are attempting new approaches to computer applications. In order to achieve wide-spread adoption of consistent energy labeling program, better modeling tools are needed. Testing suites, based on empirical data are needed to access the accuracy of new/emerging analysis tools.

Existing research:

- The U.S. Department of Energy (DOE) maintains a Building Energy Software Tools Directory that provides a comprehensive list of currently available software tools. As of December 2011, the directory contained 405 internationally-produced modeling software tools developed for the PC, Mac, and UNIX platforms and the Internet. The tools are grouped in a variety of subject areas, including Whole Building Analysis; Codes, Standards, Materials, Components, Equipment, & Systems; and others (http://apps1.eere.energy.gov/buildings/tools_directory/).
- The Lawrence Berkeley National Laboratory (LBNL) is working with the California Energy Commission and the Department of Energy to evaluate and improve tools for tracking and monitoring energy use in commercial buildings. More information on these tools can be found at http://eis.lbl.gov/ and in Appendix B.
- National Renewable Energy Laboratory (NREL) OpenStudio tool: See Appendix B for more information.

Key research questions:

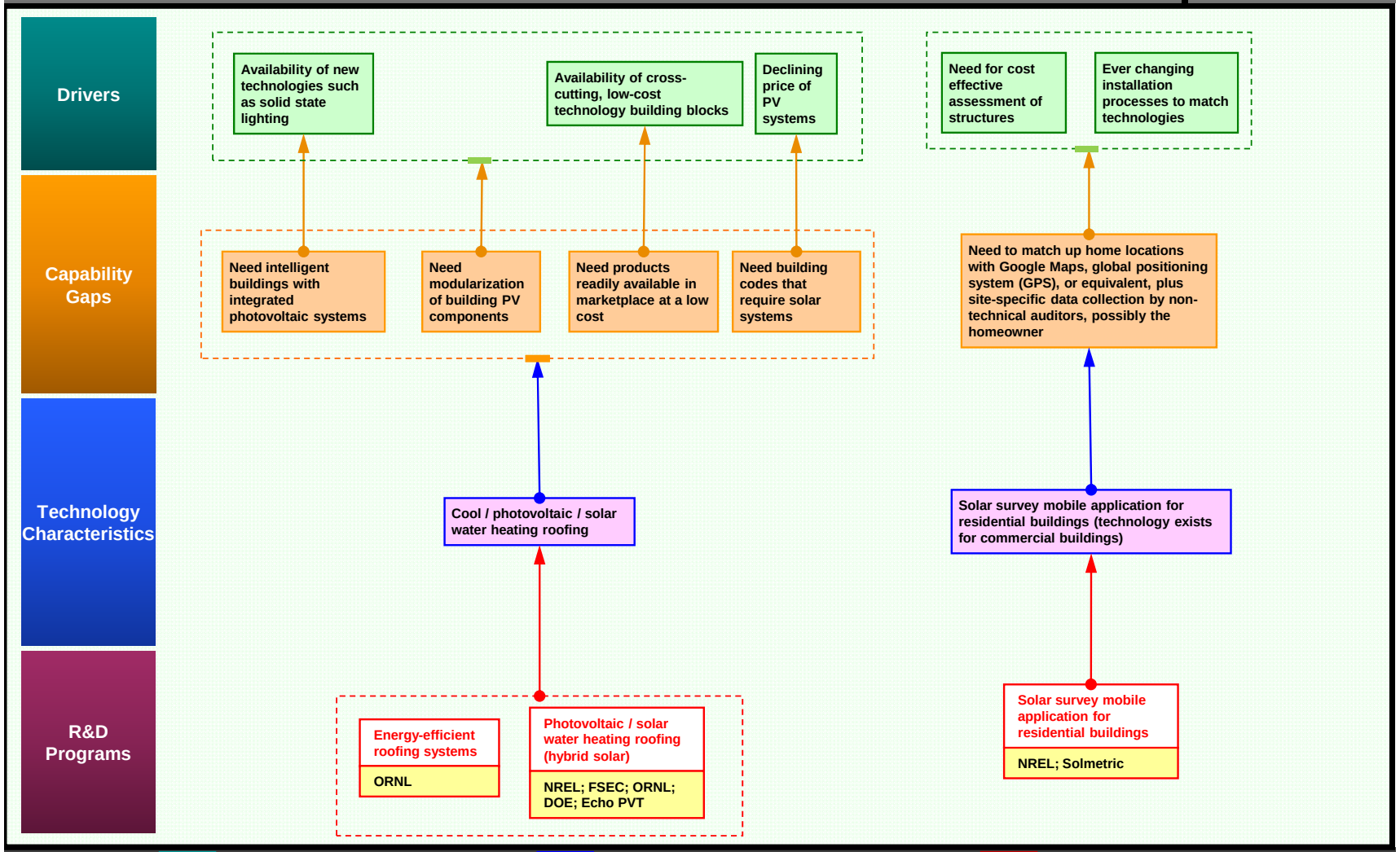
1. How accurate are existing tools?
2. How accurate are new approaches to modeling building, e.g., auto calibration, inverse modeling?
3. What are the best approaches to testing the modeling tools and using empirical data?
4. What are reasonable acceptance criteria for accuracy?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Solar / Smart Roofing (1 of 2)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Photovoltaic / solar water heating roofing (hybrid solar). Develop affordable roofing systems with integrated solar photovoltaic (PV) and solar collectors for domestic hot water (DHW) while shading the building.

Existing research: Subject matter experts identified ongoing research at the National Renewable Energy Laboratory (NREL), Florida Solar Energy Center (FSEC), Oak Ridge National Laboratory (ORNL), Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), Lawrence Berkeley National Laboratory (LBNL), and EchoFirst.

- More information about the DOE EERE's Sunshot Initiative can be found in Appendix B.
- FSEC's work in this area is likely being done by their Photovoltaics & Distributed Generation Division, but information pertaining to this research was not available as of Feb. 2012 (http://www.fsec.ucf.edu/en/research/photovoltaics/index.htm).
- NREL's research in this area can be found in Appendix B.
- LBNL's research in this area can be found in Appendix B.
- EchoFirst PV systems: http://www.echofirst.com/.

Key research questions:

1. How can hybrid solar systems be more affordable?
2. How can they be more practical for installation in retrofit?

Solar survey mobile application for residential buildings. A simple, inexpensive, accurate approach to surveying residential buildings' solar potential will assist in owners' decision-making and reduce overhead costs for installers.

Existing research: Subject matter experts identified ongoing research at .the National Renewable Energy Laboratory (NREL) and Solmetric.

- NREL's In My Backyard (IMBY) system estimates photovoltaic (PV) electricity production based on location, system size, and other factors. By using a Google Maps interface, the IMBY system easily allows one to choose an accurate PV system location, and then the IMBY tool draws applicable data from one of NREL's databases to estimate potential electricity production (http://www.nrel.gov/eis/imby/).
- Solmetric's iPV smart phone solar tracking application: http://www.solmetric.com/solmetricipv.html.

Key research questions:

1. Questions not yet specified.

Energy-efficient roofing systems. (Summary not yet provided).

Existing research: The Oak Ridge National Laboratory (ORNL) is conducting research on cool roof systems and on roof / attic systems; see Appendix B for more information.

Key research questions:

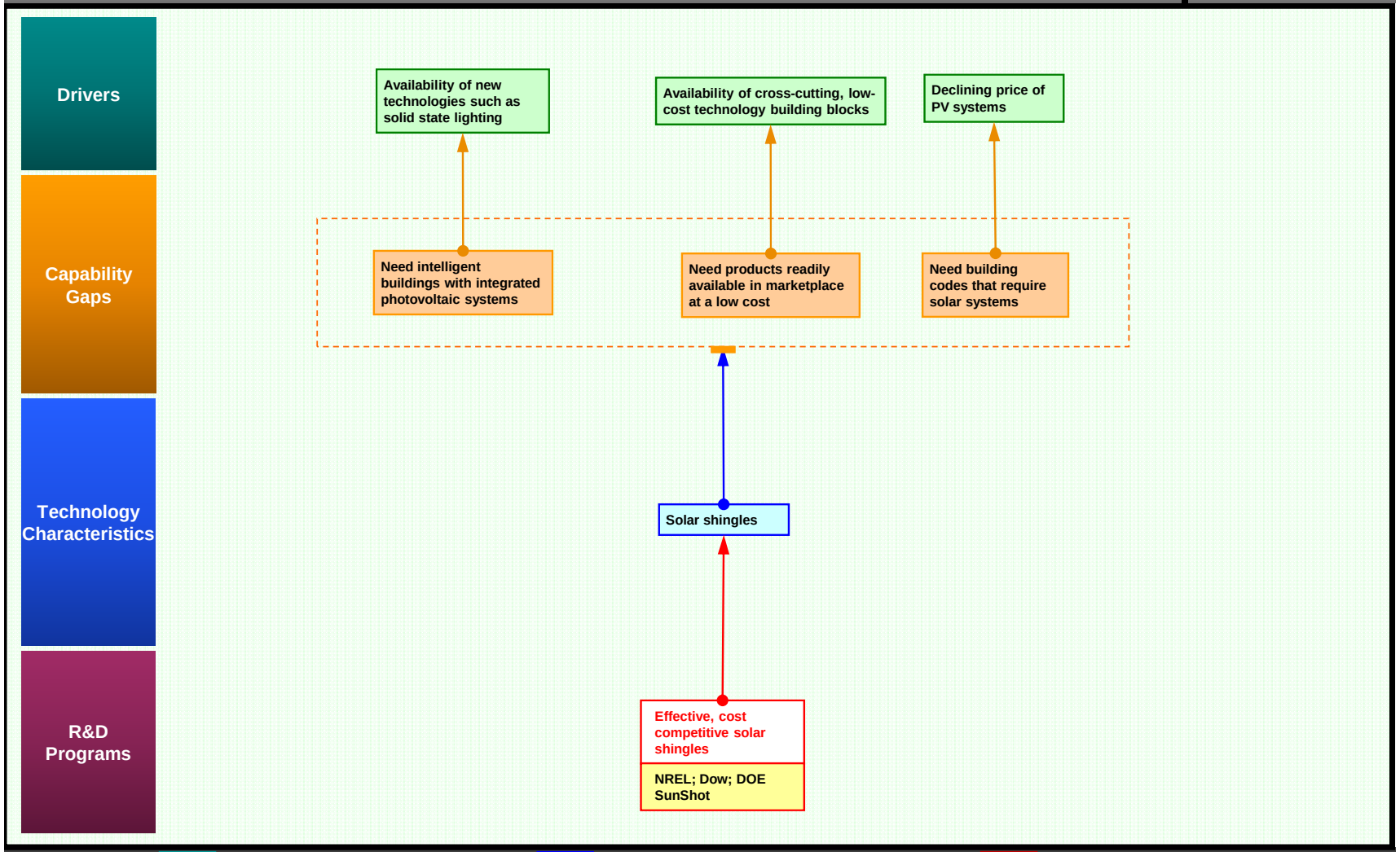
1. Questions not yet specified.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Solar / Smart Roofing (2 of 2)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Effective, cost competitive solar shingles. Building-integrated photovoltaic (PV) technologies helps make solar power more affordable and easier to incorporate into a building. Although there are currently solar shingle products in the market (i.e., DOW POWERHOUSEtm solar shingles, http://www.dowsolar.com/), these products tend to have relatively low efficiencies and higher costs when compared with standard small PV systems..

Existing research: Subject matter experts identified ongoing research at the National Renewable Energy Laboratory (NREL), Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), and the Dow Chemical Company.

- More information about the DOE EERE's Sunshot Initiative can be found in Appendix B.
- NREL's research in this area can be found in Appendix B.
- Dow Powerhouse solar shingles: http://www.dowpowerhouse.com/.

Key research questions:

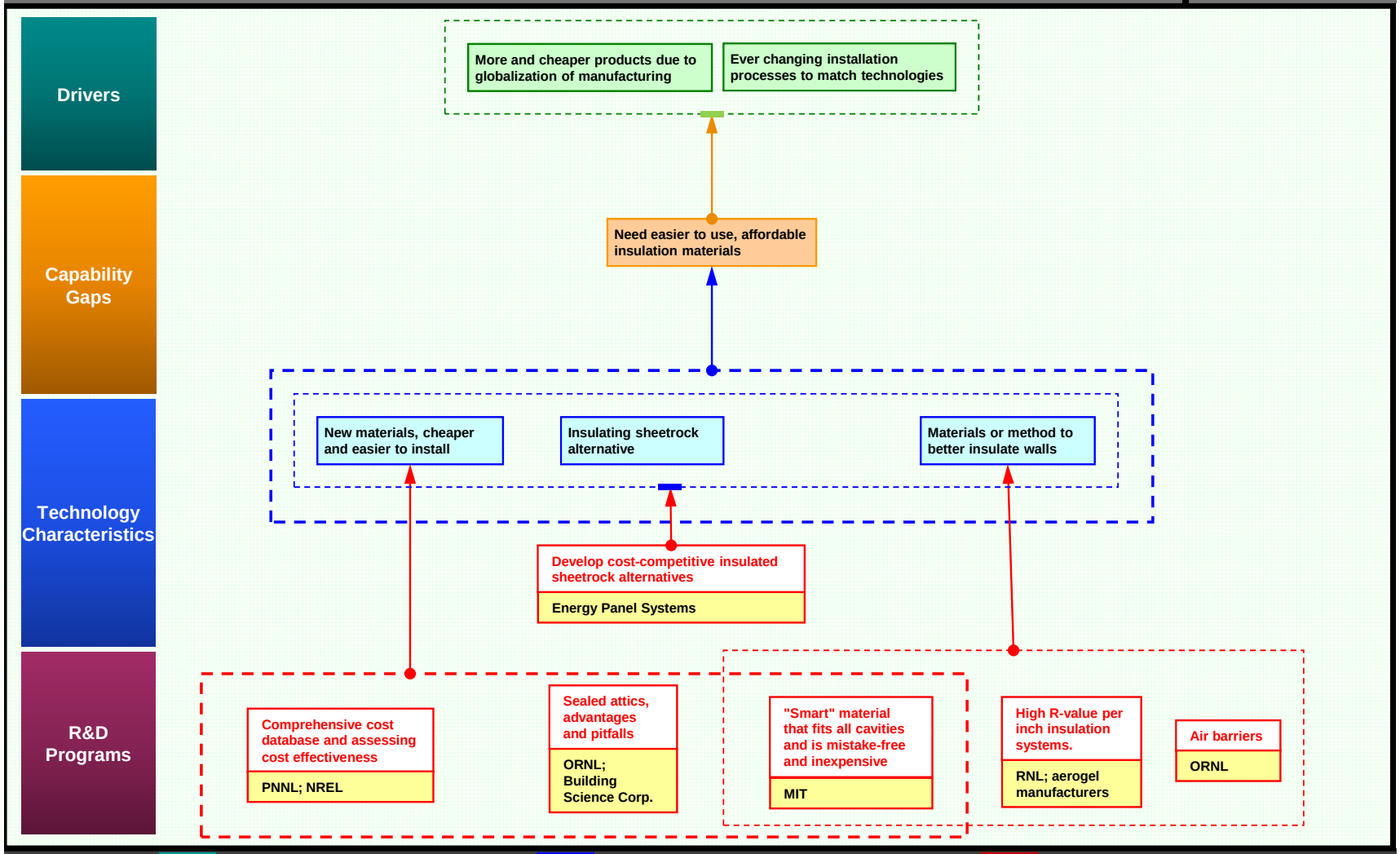
1. What is the performance/capacity for solar shingles compared to other PV tech?
2. What are the installation practices and how do they impact cost and market acceptance?
3. How durable are solar shingles? Are they easily damaged, easily maintained?
4. What are the aesthetic opportunities, color, shape, etc?
1. How easy can solar shingles be used on existing home re-roofing?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit Insulation (1 of 2)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

"Smart" material that fits all cavities and is mistake-free and inexpensive. Sprayed fiber or foam insulation is notable contenders for addressing this gap. Sprayed insulation application costs are about twice the amount of fiberglass batting, indicating the need for R&D to drive down costs.

Existing research: Subject matter experts identified ongoing research at the Massachusetts Institute of Technology (MIT); for more information about this research see Appendix B.

Key research questions:

1. Questions not yet specified.

High R-value per inch insulation systems. Develop high R-value per inch insulation systems to minimize the overall thickness or an exterior insulation application.

Existing research: Oak Ridge National Laboratory (ORNL); Aerogel manufacturers.

- *[Summaries of existing research pending]*

Key research questions:

1. What are the potential technologies?
2. How can they be incorporated into the building envelope?

Sealed attics, advantages and pitfalls. Evaluate the benefits and drawbacks of sealed attics assemblies from cost and hydrothermal perspective.

Existing research: Oak Ridge National Laboratory (ORNL); Building Science Corp.

- *[Summaries of existing research pending]*

Key research questions:

1. What do they cost compared to traditional attics>
2. Which one is better, open or closed cell foam?
3. Do they create moisture problem?
4. Is an R22 sealed attic equal to R38 traditional?

Air barriers. (Summary not yet provided).

Existing research: For Oak Ridge National Laboratory (ORNL) work in this area see Appendix B.

Key research questions:

1. Questions not yet specified.

Develop cost-competitive insulated sheetrock alternatives. A cost-effective, insulated alternative to sheetrock would help achieve Net Zero Energy retrofits in buildings where wall cavities are shallow.

Existing research: Energy Panel Systems.

- *[Summaries of existing research pending]*

Key research questions:

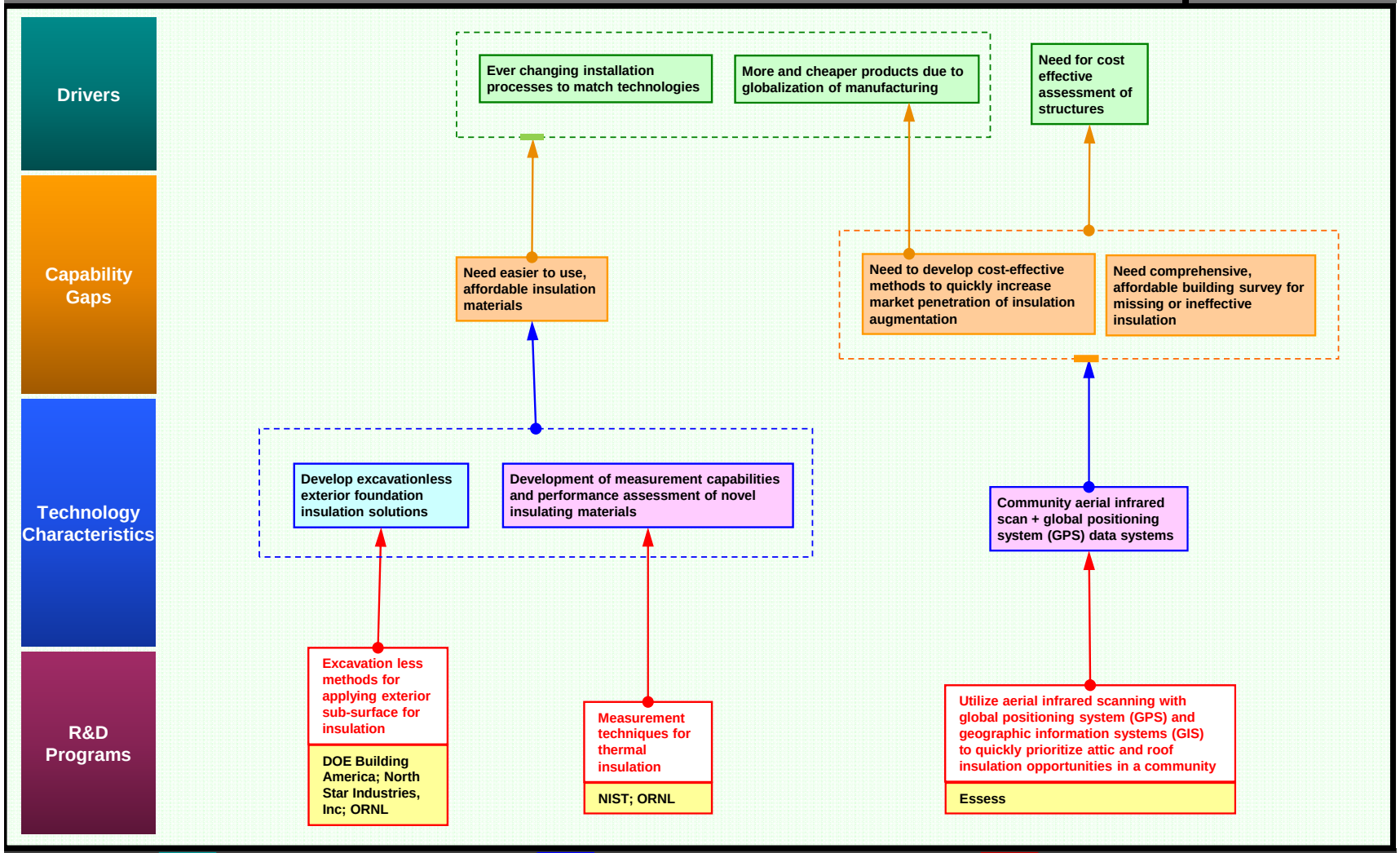
1. Develop cost and performance targets foe new materials.
2. Develop materials that meet specifications.
3. Demonstrate scalability of solutions.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit Insulation (2 of 2)**

See "Technology Area Definitions" section



Driver | Commercially Available Technology | Existing R&D Program or Project

Capability Gap | Commercially Unavailable Technology | R&D Program Requirement

R&D Program Summaries

Measurement techniques for thermal insulation. (Summary not yet provided.)

Existing research: National Institute of Standards and Technology (NIST), Oak Ridge National Laboratory (ORNL).

- *[Summaries of existing research pending]*

Key research questions:

1. How to assess R-values at new, innovative insulation technologies?

Utilize aerial infrared scanning with GPS and GIS to prioritize quickly attic and roof insulation opportunities in a community. Implementation costs of weatherization programs may be reduced and impacts greatly improved by integrating aerial infrared scanning with global positioning system (GPS) locating technologies and geographic information systems (GIS) mapping tools to aid in project identification and prioritization.

Existing research: Essess.

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Excavationless methods for applying exterior sub-surface for insulation. Develop new cost effective techniques for applying exterior insulation to existing foundations.

Existing research: Building America, North Star Industries, Inc.

- *[Summaries of existing research pending]*

Key research questions:

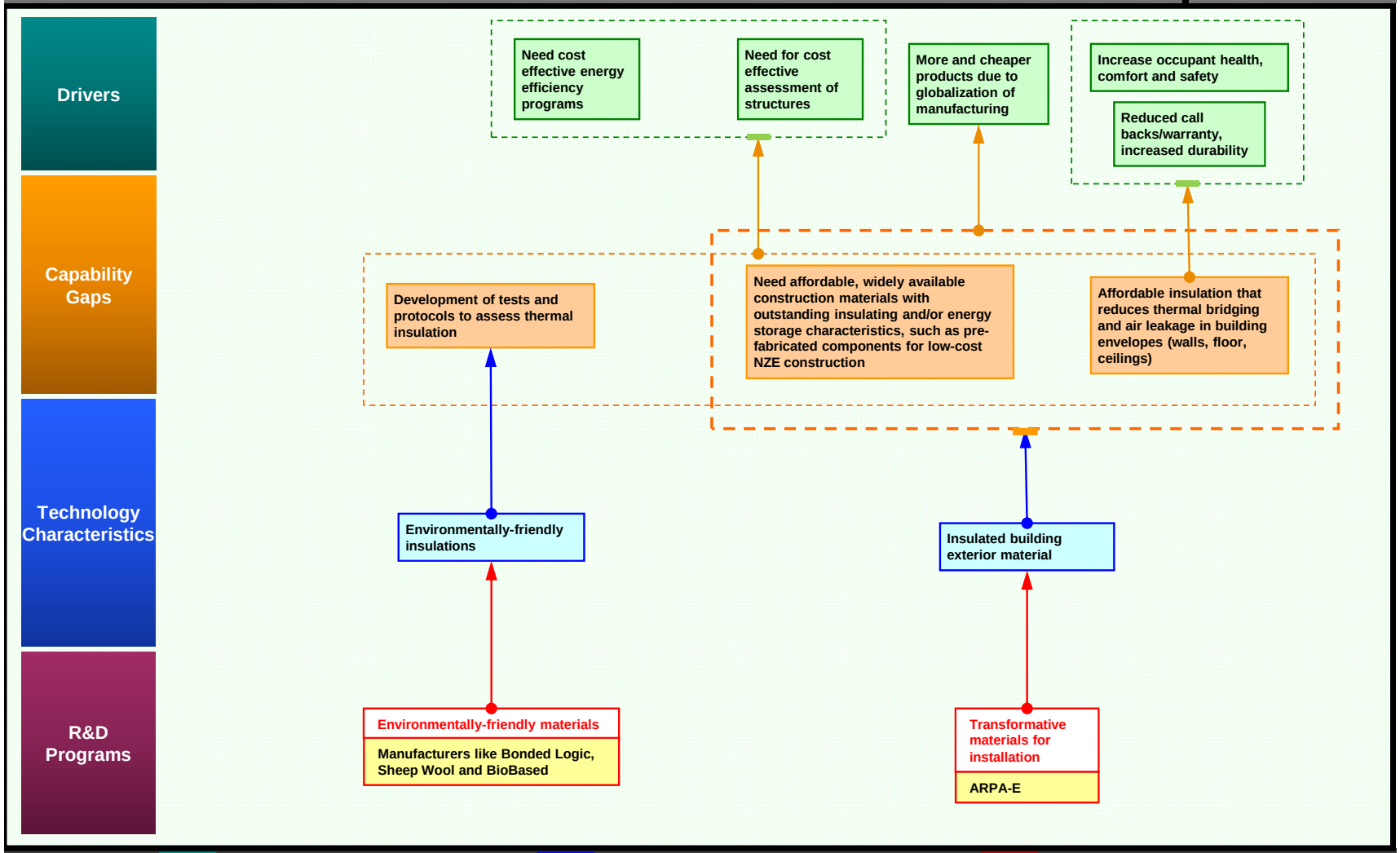
1. Cost and performance targets for systems (cheaper than interior insulation).
2. Scalable, easy techniques.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **New Construction Insulation (1 of 4)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Transformative materials for installation. A "linable" material whose properties change with temperature and humidity conditions (e.g. changes in emissivity, permeability, conductivity, etc.).

Existing research: Department of Energy (DOE) Advanced Research Projects Agency - Energy (ARPA-E).

- *[Summaries of existing research pending]*

Key research questions:

1. Set target performance and cost goals.
2. Material properties that change with temperature.
3. Energy savings potential.
4. What are key drivers and variables?

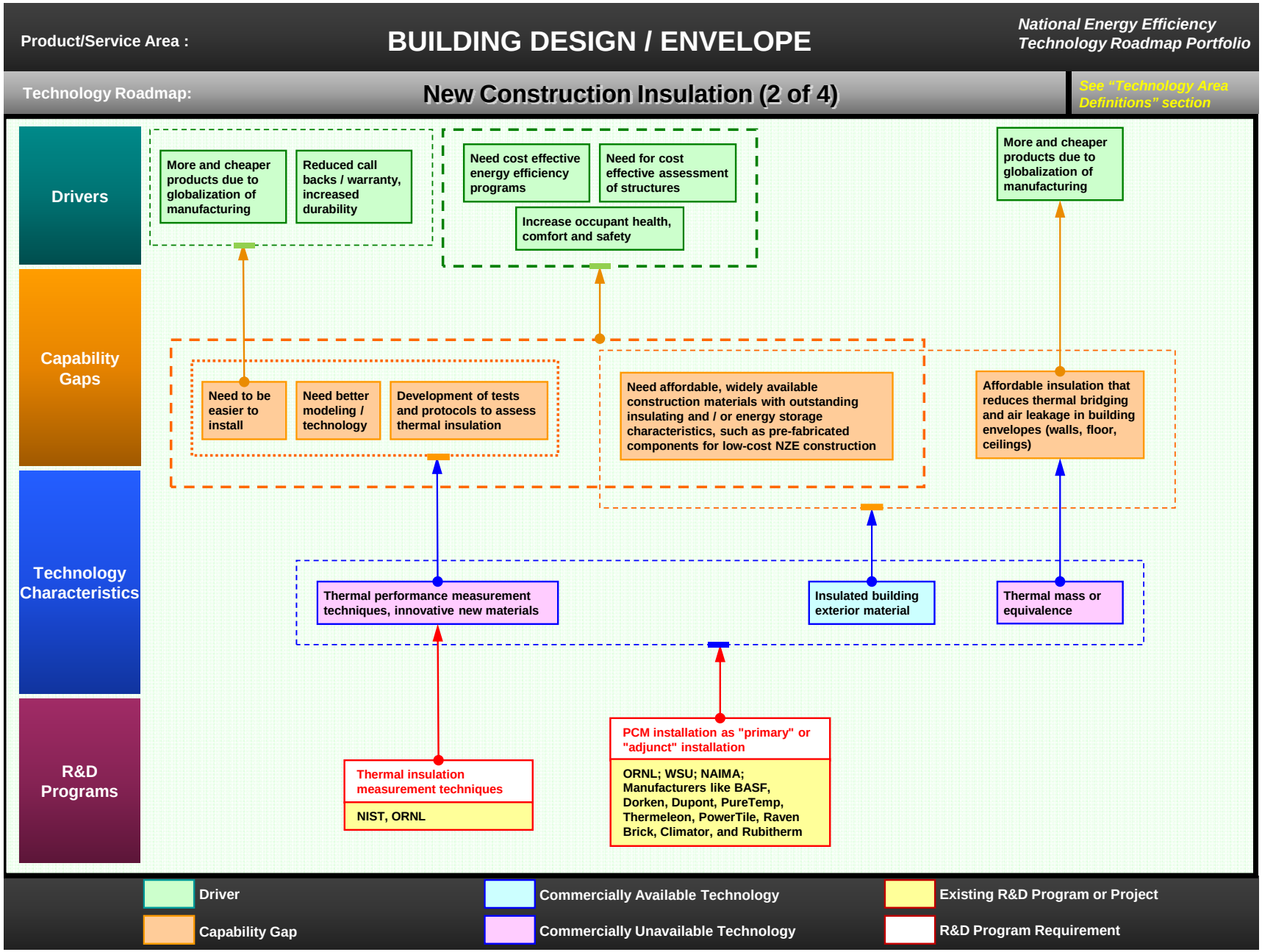
Environmentally-friendly materials. Identify environmental impacts of existing insulation materials.

Existing research: Manufacturers like Bonded Logic, Sheep Wool and BioBased.

- *[Summaries of existing research pending]*

Key research questions:

1. Protocol for evaluating "greenness" of insulations?
2. Assess environmental impact of existing insulations?
3. Develop "Environmental Product Declaration (EPD)" and "Health Product Declaration (HPD)" systems for insulations.


Product/Service Area :
BUILDING DESIGN / ENVELOPE
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
New Construction Insulation (2 of 4)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
More and cheaper products due to globalization of manufacturing
Reduced call backs / warranty, increased durability
Need cost effective energy efficiency programs
Need for cost effective assessment of structures
Increase occupant health, comfort and safety
More and cheaper products due to globalization of manufacturing
Need to be easier to install
Need better modeling / technology
Development of tests and protocols to assess thermal insulation
Need affordable, widely available construction materials with outstanding insulating and / or energy storage characteristics, such as pre-fabricated components for low-cost NZE construction
Affordable insulation that reduces thermal bridging and air leakage in building envelopes (walls, floor, ceilings)
Thermal performance measurement techniques, innovative new materials
Insulated building exterior material
Thermal mass or equivalence
Thermal insulation measurement techniques
NIST, ORNL
PCM installation as "primary" or "adjunct" installation
ORNL; WSU; NAIMA; Manufacturers like BASF, Dorken, Dupont, PureTemp, Thermeleon, PowerTile, Raven Brick, Climator, and Rubitherm
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

PCM installation as "primary" or "adjunct" installation. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL), Washington State University (WSU), North American Insulation Manufacturers Association (NAIMA).

- *[Summaries of existing research pending]*

Key research questions:

1. Cost effectiveness, performance goals.
2. Cycling, time-hysteresis characteristics.
3. Structural integrity, installations.

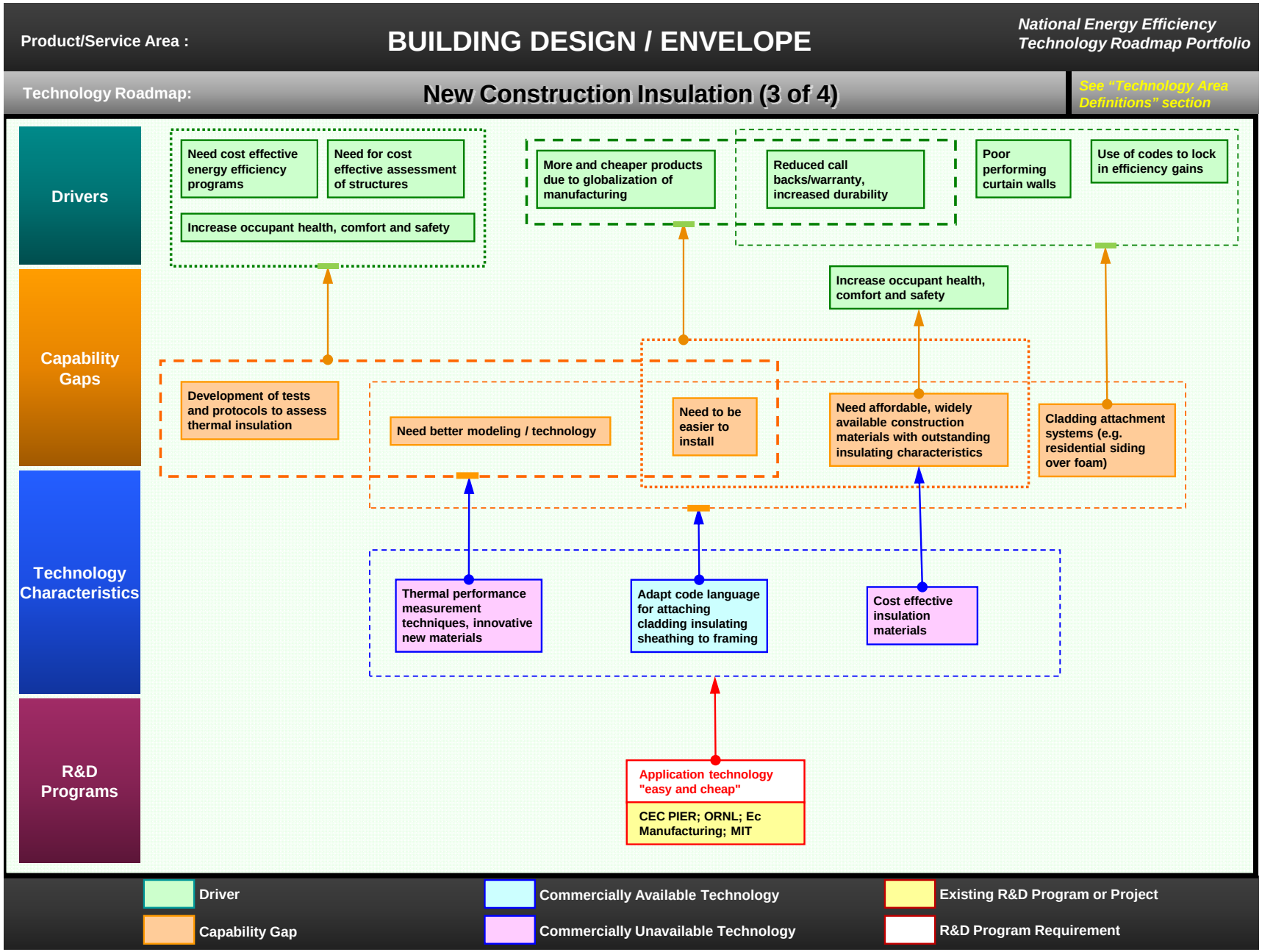
Thermal insulation measurement techniques. (Summary not yet provided.)

Existing research: National Institute of Standards and Technology (NIST).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.


Product/Service Area :
BUILDING DESIGN / ENVELOPE
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
New Construction Insulation (3 of 4)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Need cost effective energy efficiency programs
Need for cost effective assessment of structures
Increase occupant health, comfort and safety
More and cheaper products due to globalization of manufacturing
Reduced call backs/warranty, increased durability
Poor performing curtain walls
Use of codes to lock in efficiency gains
Increase occupant health, comfort and safety
Development of tests and protocols to assess thermal insulation
Need better modeling / technology
Need to be easier to install
Need affordable, widely available construction materials with outstanding insulating characteristics
Cladding attachment systems (e.g. residential siding over foam)
Thermal performance measurement techniques, innovative new materials
Adapt code language for attaching cladding insulating sheathing to framing
Cost effective insulation materials
Application technology "easy and cheap"
CEC PIER; ORNL; Ec Manufacturing; MIT
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Application technology "easy and cheap." To achieve widespread use of more efficient building insulation, develop new materials that are cost-competitive with existing materials and that are easy to install.

Existing research: California Energy Commission (CEC) Public Interest Energy Research (PIER) program, Oak Ridge National Laboratory (ORNL), Ec Manufacturing, Massachusetts Institute of Technology (MIT).

- ORNL developed a panelized wall system in 2010 with foam core insulation that can be easily assembled, is airtight, and is extremely energy efficient (http://www.ornl.gov/adm/partnerships/factsheets/10-G01077_ID1581.pdf).
- In 2010, Ec Manufacturing, LLC, of Colorado introduced to the market its rSTUD line of insulated, thermally-broken dimensional lumber products (http://rstud.com/, http://www.jetsongreen.com/2010/10/new-thermally-broken-rstud-lumber.html#).
- As of 2008, PIER researchers are exploring the feasibility of using a low-cost, perlite-based ceramic insulator material for buildings (http://www.energy.ca.gov/pier/portfolio/Content/06/EISG/Improved%20Insulation%20for%20Buildings.htm).
- MIT has been researching insulated concrete forms to determine the advantages over conventional wood-framed construction. See Appendix B for more information.

Key research questions:

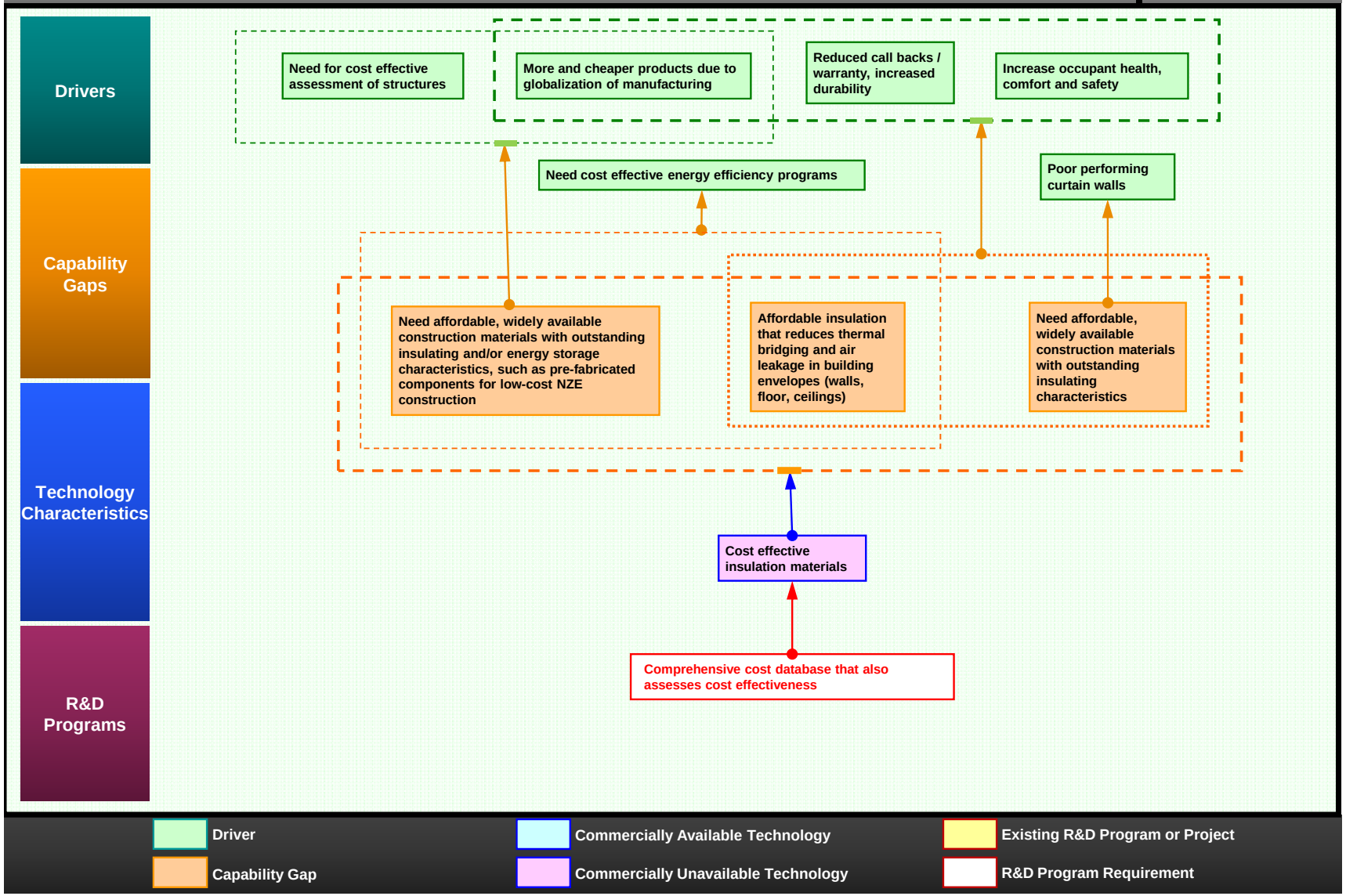
1. Questions not yet specified.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **New Construction Insulation (4 of 4)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Comprehensive cost database that also assesses cost effectiveness. Collect nationally and regionally material and installation cost data at component and system level. Make recommendations for assessing cost effectiveness.

Subject matter experts identified two databases, one at the Pacific Northwest National Laboratory (PNNL) and the other at the National Renewable Energy Laboratory (NREL). Both of these are just tools and do not provide cost assessment.

- NREL's National Residential Efficiency Measures Database: http://www.nrel.gov/ap/retrofits/index.cfm.
- PNNL's Building Component Cost Community (BC3): http://bc3.pnnl.gov/wiki/index.php/Main_Page.

Existing research: None identified.

Key research questions:

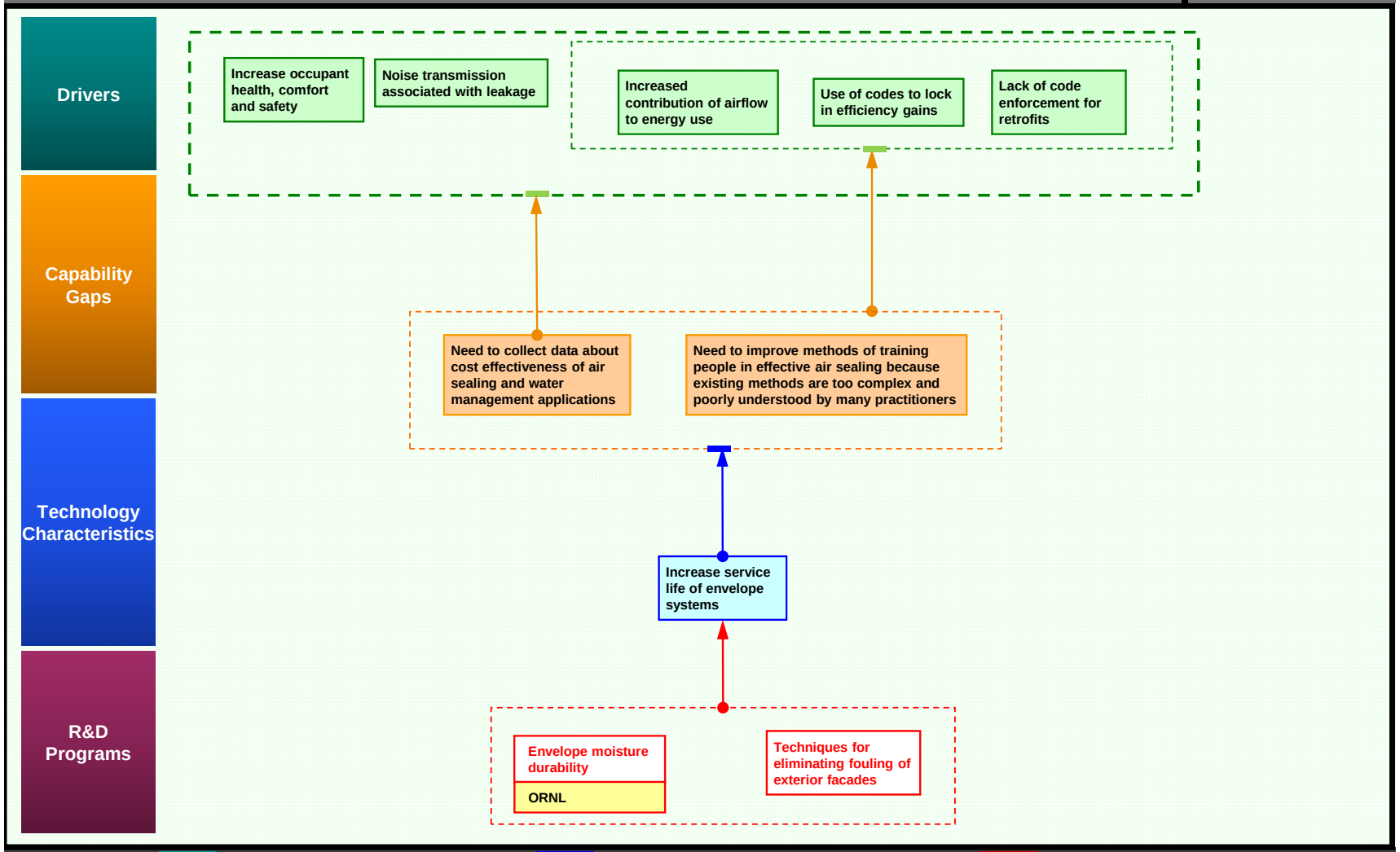
1. How should we assess cost effectiveness of building envelope systems (air, vapor, thermal barriers).
2. What are the key variables that impact material and installation costs?
3. Create database of available cost data for residential EE measures.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Air/Water Management (1 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Envelope Moisture Durability. (Summary not yet provided.)

Existing research: For Oak Ridge National Laboratory (ORNL) research in this area, see Appendix B.

Key research questions:

1. Questions not yet specified.

Techniques for eliminating fouling of exterior facades. Heavily insulated facades have exterior temperature close to ambient that exacerbate the likelihood of condensation on the surface. Develop techniques to handle this problem

Existing research: None identified.

Key research questions:

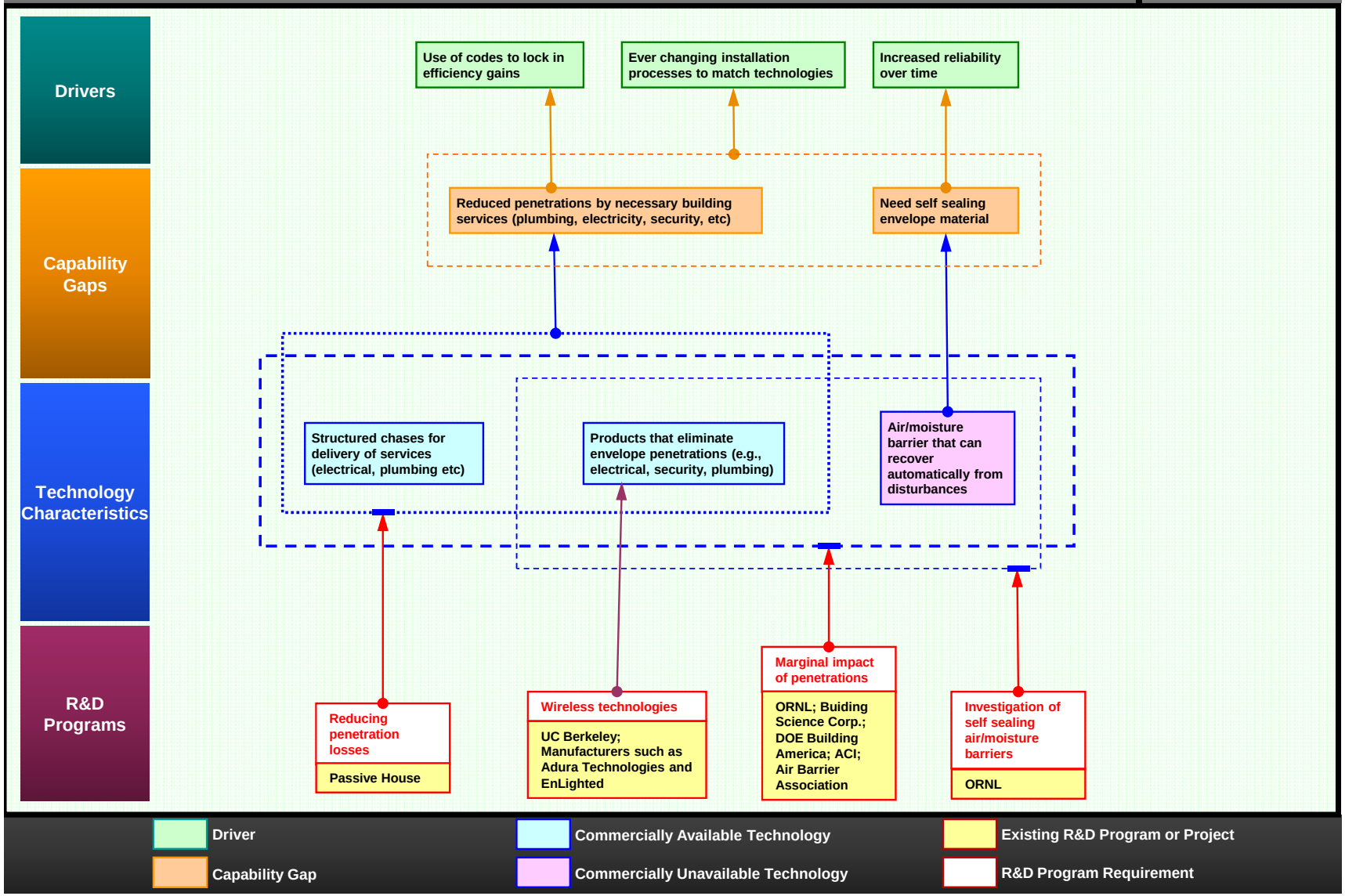
1. Do Phase Change Materials (PCMs) blended in exterior facades work?
2. Can we develop environmentally friendly biocides?
3. Can we develop variable emittance coatings?
4. Can we develop aesthetically pleasing low emittance coatings?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Air/Water Management (2 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Marginal impact of penetrations. Inventory variants types of wall penetrations and assess marginal impact to envelope losses.

Existing research: Oak Ridge National Laboratory (ORNL); Building Science Corp; Department of Energy (DOE) Building America program; Affordable Comfort Institute (ACI); Air Barrier Association.

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Wireless technologies. Develop wireless technologies that eliminate or reduce penetrations/chases in building envelopes.

Existing research: Subject matter experts identified ongoing research at the University of California at Berkeley, and at various manufacturers including Adura Technologies and EnLighted.

- *[Summaries of existing research pending]*

Key research questions:

1. What wireless technologies are available to provide electrical/security/control services?
2. Can we cost effectively produce technologies that provide these services?

Reducing penetration losses. Technology form factors that reduce/eliminate penetrations from electrical, plumbing, or security systems installation.

Existing research: Passive House Institute (http://passivehouse.us/passiveHouse/PHIUSHome.html).

- *[Summaries of existing research pending]*

Key research questions:

1. What are the marginal impact of varies wall penetrations (on building loss) to prioritize?
2. What type of structured/centralized conduit/harness systems can be deployed to minimize unintentional loss paths (between floors, walls)?
3. What are new types of sleeves, grommets, etc that provide higher reliability in sealing penetration?

Investigation of self sealing air/moisture barriers. Characterize the robustness of existing air sealing and moisture barriers system with respect to building aging. Develop and test systems that are more failure-resistant.

Existing research: For Oak Ridge National Laboratory (ORNL) research in this area, see Appendix B.

Key research questions:

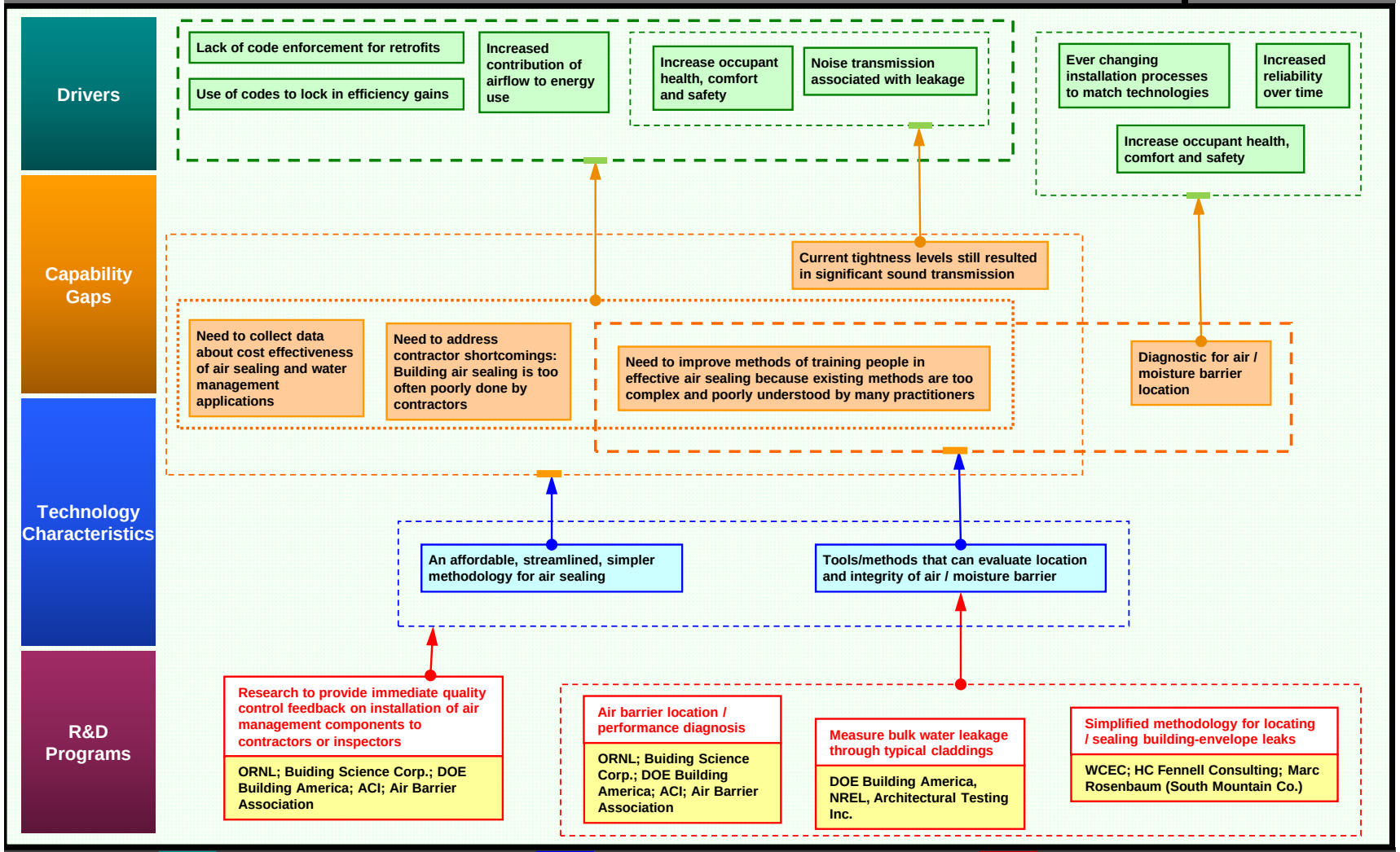
1. How do current air sealing and air barriers systems respond to settling, earthquakes and/or penetration?
2. Can we produce sealing system that is impervious to earthquakes, settling and even penetrations?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Retrofit and New Construction Air/Water Management (3 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Simplified methodology for locating/sealing building-envelope leaks. Develop methodology for locating, sealing leaks and measure the performance in building envelopes in both new and existing construction with respect to tightness level provided, percentage of leak reduction, etc.

Existing research: University of California at Davis Western Cooling Efficiency Center (WCEC).

- *[Summaries of existing research pending]*

Key research questions:

1. What tightness level can be achieved in new construction and existing homes with the simplified methodologies?
2. At what stage should the technology be applied?
3. How much does it cost to apply the technology in new retrofit

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Research to provide immediate quality control feedback on installation of air management components to contractors or inspectors. While contractors generally want to do a good job, too often a job is poorly done because of lack of information. Inspectors have difficulty verifying quality.

Existing research: Oak Ridge National Laboratory (ORNL); Building Science Corp; Department of Energy (DOE) Building America program, Affordable Comfort Institute (ACI); Air Barrier Association.

- *[Summaries of existing research pending]*

Key research questions:

1. What are the key installation processes that need to be verified during construction/renovation?
2. What products are used during those processes?
3. What indicator would be effective and possible in a construction environment?

Measure bulk water leakage through typical claddings. Hydrothermal performance of wall systems is subject to the control of bulk water intrusion due to wind-driven rain.

Existing research: American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard 160, Criteria for Moisture-Control Design Analysis in Buildings (http://sspc160.ashraepcs.org/).

- *[Summaries of existing research pending]*

Key research questions:

1. How much water penetrates cladding?
2. Develop standard test procedure and envelope systems that can handle these loads.

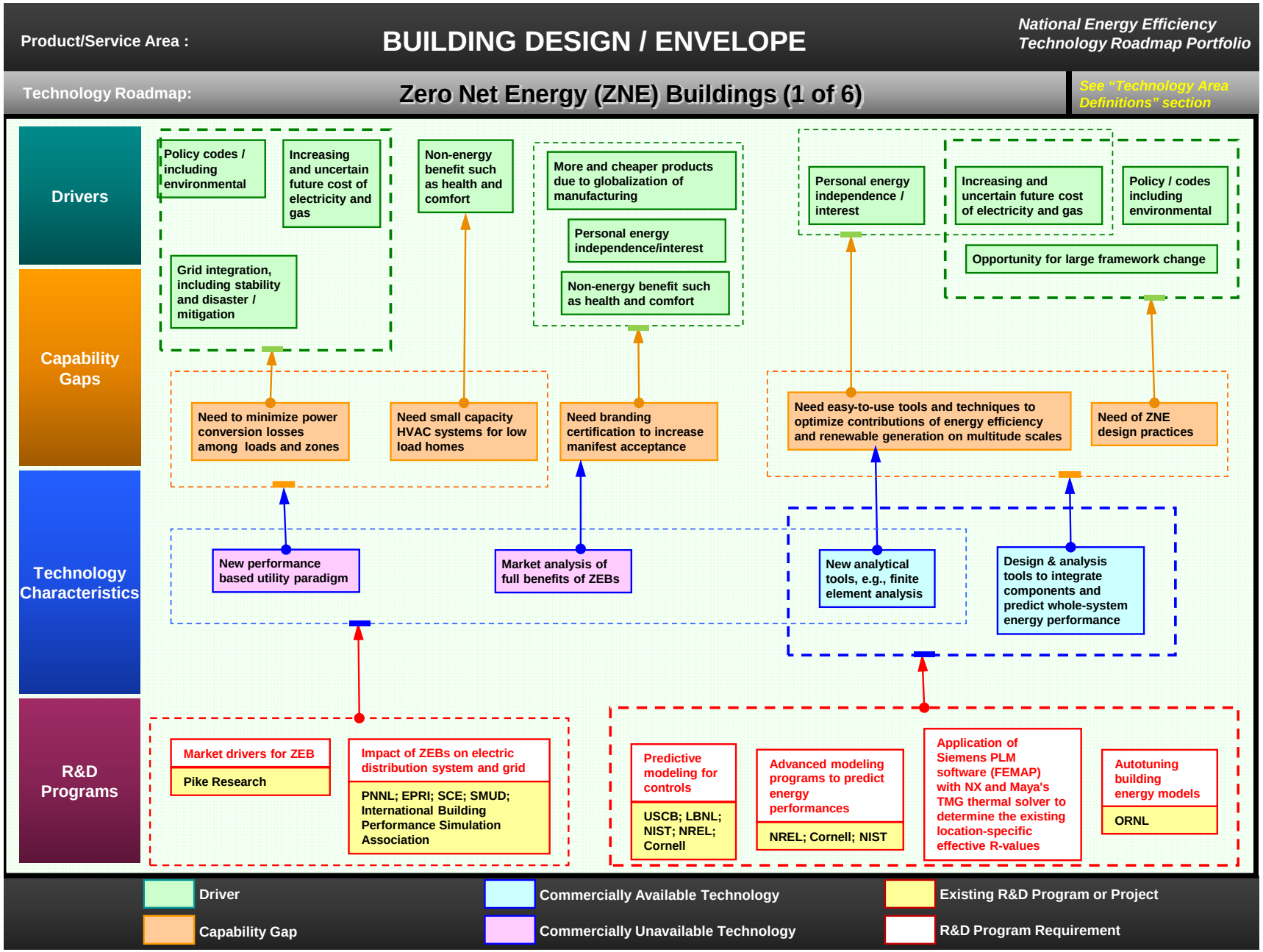
Air barrier location/performance diagnosis. Develop and test methodologies to separately measure the tightness of building envelopes at the interior and exterior planes. The goal is to be able to understand and improve the air flow, air intrusion and water intrusion performance of building envelopes.

Existing research: Oak Ridge National Laboratory (ORNL); Building Science Corp; Department of Energy (DOE) Building America program; Affordable Comfort Institute (ACI); Air Barrier Association.

- *[Summaries of existing research pending]*

Key research questions:

1. How can we separately determine leakage of interior and exterior planes of the building envelopes?
2. What are typical leakage levels at the interior and exterior planes of building envelopes?
3. What are the energy implications of improving air tightness at the interior and exterior planes of building envelopes?


Product/Service Area :
BUILDING DESIGN / ENVELOPE
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Zero Net Energy (ZNE) Buildings (1 of 6)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Policy codes / including environmental
Increasing and uncertain future cost of electricity and gas
Grid integration, including stability and disaster / mitigation
Non-energy benefit such as health and comfort
More and cheaper products due to globalization of manufacturing
Personal energy independence/interest
Non-energy benefit such as health and comfort
Personal energy independence / interest
Increasing and uncertain future cost of electricity and gas
Policy / codes including environmental
Opportunity for large framework change
Need to minimize power conversion losses among loads and zones
Need small capacity HVAC systems for low load homes
Need branding certification to increase manifest acceptance
Need easy-to-use tools and techniques to optimize contributions of energy efficiency and renewable generation on multitude scales
Need of ZNE design practices
New performance based utility paradigm
Market analysis of full benefits of ZEBs
New analytical tools, e.g., finite element analysis
Design & analysis tools to integrate components and predict whole-system energy performance
Market drivers for ZEB
Pike Research
Impact of ZEBs on electric distribution system and grid
PNNL; EPRI; SCE; SMUD; International Building Performance Simulation Association
Predictive modeling for controls
USCB; LBNL; NIST; NREL; Cornell
Advanced modeling programs to predict energy performances
NREL; Cornell; NIST
Application of Siemens PLM software (FEMAP) with NX and Maya's TMG thermal solver to determine the existing location-specific effective R-values
Autotuning building energy models
ORNL
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

General note on Zero Net Energy R&D: In late 2011, The California Public Utilities Commission (CPUC) and the California Energy Commission (CEC) held a workshop to develop a Research and Technology Action Plan as an integral element of the process of implementing the California Energy Efficiency Strategic Plan (http://www.cpuc.ca.gov/PUC/energy/Energy+Efficiency/eesp/). This Strategic Plan includes a section focused on Net Zero Energy (NZE) technologies for residential and commercial buildings (http://www.cpuc.ca.gov/NR/rdonlyres/6C2310FE-AFE0-48E4-AF03-530A99D28FCE/ 0/ZNEActionPlanFINAL83110.pdf). As of Feb. 8 2012, Edward Vine, Program Director for Planning and Analysis at the California Institute for Energy and Environment (http://uc-ciee.org/technical-experts/15/dpeople), had revised a Research and Technology Gap Analysis on ZNEbuildings that he originally compiled in June 2011.

Net Zero Energy (NZE) is often also referred to as Zero Net Energy (ZNE). "ZEB" is the acronym for Zero Energy Building.

Advanced modeling programs to predict energy performances. Create energy modeling platform that enable designer to use simulation in the design process to effectively make decision that drive solutions to low-energy design.

Existing research: National Institute for Standards and Technology (NIST), National Renewable Energy Laboratory (NREL).

- NIST's work in this area is identified in Appendix B.
- NREL's work in this area is identified in Appendix B.

Key research questions:

1. What are the key operational failure points and how easy are they to fix? What technologies can fix these issues?
2. What other industries use diagnostics and how does that apply to building?
3. How can control be standardized to make installation easier?

Predictive modeling for controls . Integrating and operating the variety of energy technologies required to achieve Net Zero Energy requires advanced modeling and controls.

Existing research: Research is ongoing at Cornell University, the Lawrence Berkeley National Laboratory (LBNL), the University of California Santa Barbara (UCSB) Institute for Energy Efficiency (IEEE), the National Institute for Standards and Technology (NIST), and the National Renewable Energy Laboratory (NREL).

- LBNL's work in this area is identified in Appendix B.
- The Buildings & Design Solutions Group of UCSB's Institute for Energy Efficiency is doing research into economically viable Zero Net Energy building systems; see Appendix B for more information.
- NIST's work in this area is identified in Appendix B.
- A team within the Cornell University Program of Computer Graphics is working on a three-year grant funded by the Department of Energy (using American Recovery and Reinvestment Act (ARRA) funds) to use computer building simulations to streamline green design, the Green Building Design Computer Simulation Software project; see Appendix B for more information.
- NREL's work in this area is identified in Appendix B.

Key research questions:

1. Understand how the design decisions are made.
2. Identify how to shift the decision process toward energy-driven design.
3. Identify how to incorporate building science in the design process.
4. Identify how to make design teams more interdisciplinary rather than just multidisciplinary.
5. Understand how the procurement process can drive performance based design.

Continued . . .

Impact of ZEBs on electric distribution system and grid. Measure and summarizing distribution system and grid integration of large penetration ZEBs and its variation in different implementation (housing and mixed use).

Existing research: Pacific Northwest National Laboratory (PNNL), Electric Power Research Institute (EPRI), Southern California Edison (SCE), Sacramento Municipal Utility District (SMUD), International Building Performance Simulation Association (IBPSA).

- IBPSA: http://www.ibpsa.org/.
- *[Summaries of other existing research pending]*

Key research questions:

1. What are the potential benefits of commercially implementation of ZEBs, including peak reduction, distribution system, efficiency, power quality, depend ability?
2. Find best opportunities to measure item described above.

Autotuning building energy models. (Summary not yet provided.)

Existing research: For Oak Ridge National Laboratory (ORNL) research in this area, see Appendix B.

Key research questions:

1. Question

Market drivers for ZEB. Need to understand what drives builders and/or developers to build ZEBs and what drives consumers/tenants to demand them.

Existing research: Pike Research.

- Pike Research (merged with Navigant): http://www.pikeresearch.com/research/zero-energy-buildings.

Key research questions:

1. What are the perceived benefits of ZEBs for builders/developers and consumers?
2. How can the above information be made relevant to larger market?

Application of Siemens PLM software (FEMAP) with NX and Maya's TMG thermal solver to determine the existing location-specific effective R-values. Envelope assembly details: 1) CAD drawing for each detail (92 in BC), 2) finite element analysis, 3) Identification of technologies to eliminate thermal bridges (technical potential and economic potential).

Existing research: None identified.

Key research questions:

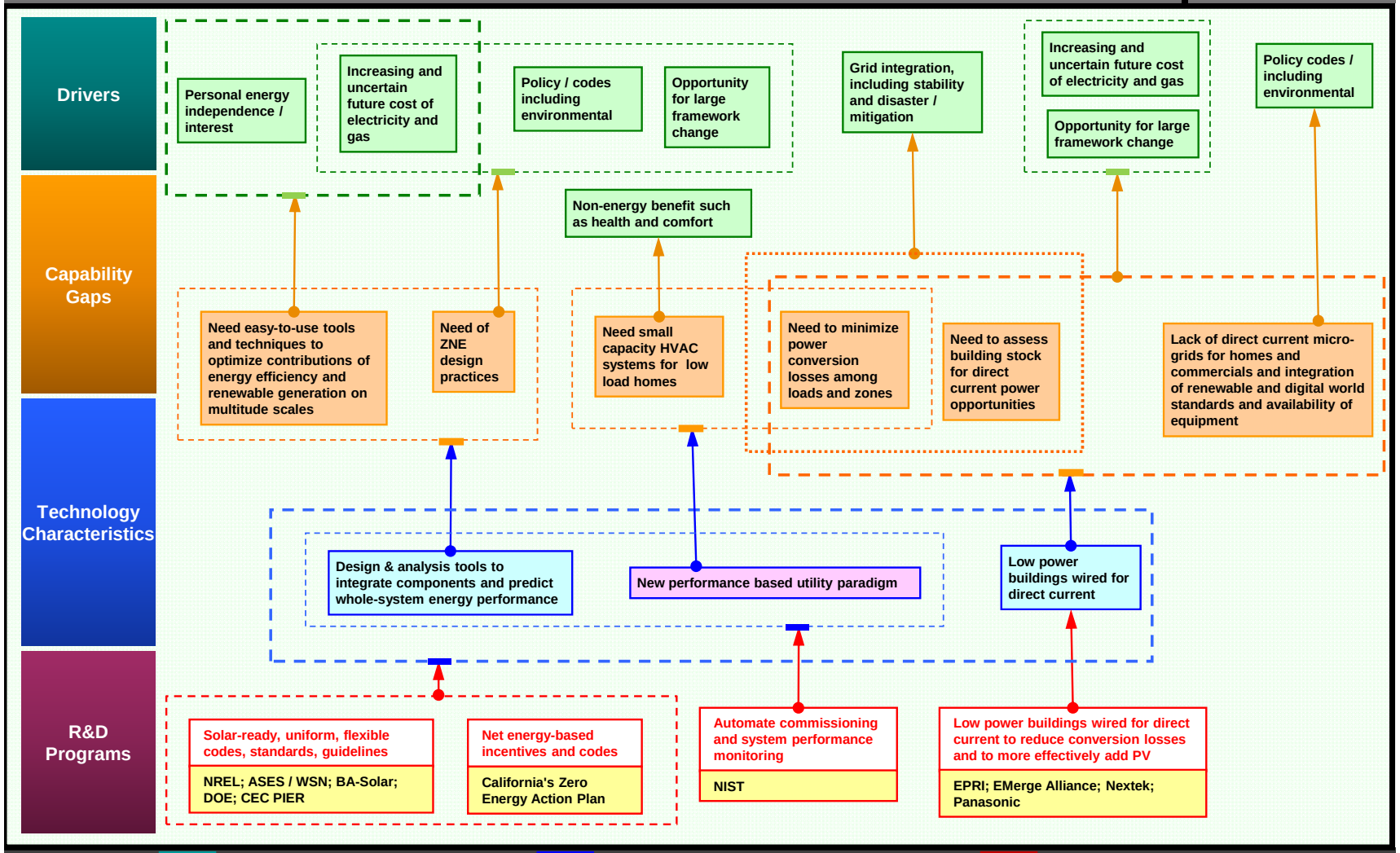
1. What level of controls is needed for ZEBs? If good design can be used, can control be reduces?
2. What topology of controls should be used? How much centralized Vs. distributed?
3. What (if any) models and what complexity of models are needed? If complex models are needed, what is the pathway to collect that data?
4. How much improvement can be made with predictive controls compared with classical feedback controls?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Zero Net Energy (ZNE) Buildings (2 of 6)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Solar-ready, uniform, flexible codes, standards, guidelines. Improve structural, fire safety, mechanical, plumbing, electrical and utility metering which stimulate M.T. while increasing cost effectiveness, quality installation, and health and safety.

Existing research: Subject matter experts identified ongoing research at the National Renewable Energy Laboratory (NREL), Department of Energy (DOE), BA-Solar, the California Energy Commission (CEC) Public Interest Energy Research (PIER) program, and "ASES/WSN."

- *[Summaries of existing research pending]*

Key research questions:

1. Determine existing research efforts whether they are completed or underway.
2. Identify gaps and areas to improve.
3. General stakeholders and industry-level of interest and issues around it.
4. What are the cost and benefits to retrofit with solar ready?

Low power buildings wired for direct current to reduce conversion losses and to more effectively add PV. Design buildings with both AC and DC outlets so that DC-ready electronic appliances can use the DC directly, eliminating conversion losses.

Existing research: E Source reported that, as of January 2011, most research in this area in the United States is focused on commercial applications and DC-wired data centers; therefore, there is an R&D gap for DC-wired residential buildings. Some of the findings from this research may cross-over into the residential sector, and there is work being done in Japan. Research is ongoing at the Electric Power Research Institute (EPRI), EMerge Alliance, Nextek, and Panasonic.

- The Electric Power Research Institute (EPRI) is conducting research on DC power for data centers and high voltage direct current (HVDC) systems that may have that results that can cross-over into commercial and/or residential applications; see Appendix B for more information.
- EMerge Alliance developed their "EMerge Standard" in 2009 to supplement ASHRAE building standards for DC low-voltage power distribution within commercial building interiors. See Appendix B for more information.
- Nextek Power Systems (http://www.nextekpower.com/) and Redwood Systems (www.redwoodsystems.com) are developing different DC power systems for commercial and industrial buildings.
- In Japan, Panasonic Electric Works is doing research on what they are calling "hybrid housing"—homes supplied with both AC and DC power (http://panasonic.net/pew/).

Key research questions:

1. Topology what is needed for power distribution.
2. How to wire AC/DC systems?
3. What is the architecture for integration of the future building power system?
4. How or should DC voltages be converted?

Net energy-based incentives and codes. Develop technical foundation for net-energy based incentives and codes as alternative compliance path.

Existing research: California's Zero Energy Action Plan (http://www.cpuc.ca.gov/NR/rdonlyres/6C2310FE-AFE0-48E4-AF03-530A99D28FCE/0/ZNEActionPlanFINAL83110.pdf).

- *[Summaries of existing research pending]*

Key research questions:

1. Define cost benefits of performance-based compliance path including net zero definition.
2. Conduct case study based on one or several utility/region.
3. Define requirements to limit risks and unintended consequences.
4. Define low cost measurements and validation requirements.

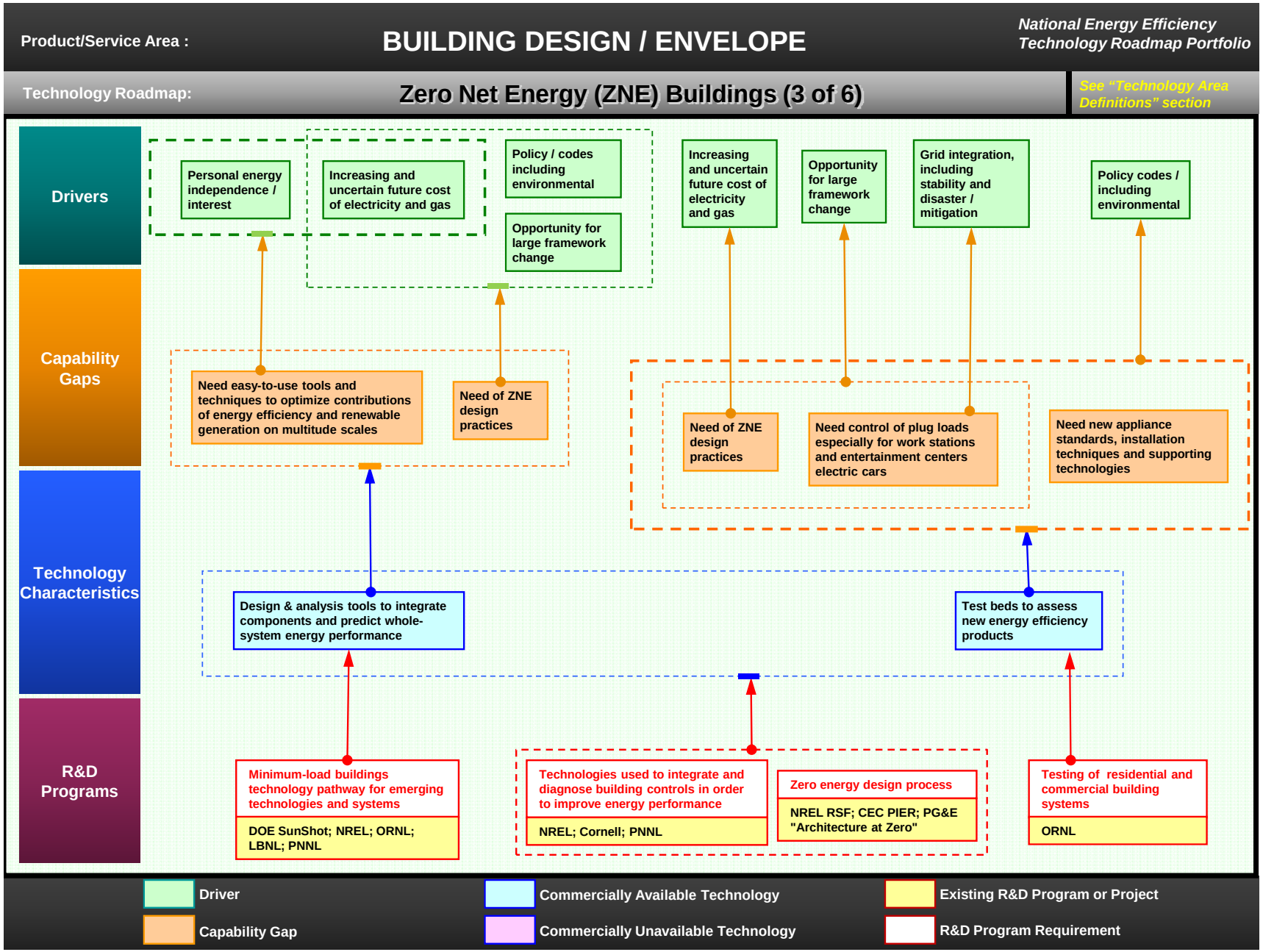
Continued . . .

Automate commissioning and system performance monitoring. (Summary not yet provided.)

Existing research: For National Institute of Standards and Technology (NIST) ongoing research in this area, see Appendix B.

Key research questions:

1. Question


Product/Service Area :
BUILDING DESIGN / ENVELOPE
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Zero Net Energy (ZNE) Buildings (3 of 6)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Personal energy independence / interest
Increasing and uncertain future cost of electricity and gas
Policy / codes including environmental
Opportunity for large framework change
Increasing and uncertain future cost of electricity and gas
Opportunity for large framework change
Grid integration, including stability and disaster / mitigation
Policy codes / including environmental
Need easy-to-use tools and techniques to optimize contributions of energy efficiency and renewable generation on multitude scales
Need of ZNE design practices
Need of ZNE design practices
Need control of plug loads especially for work stations and entertainment centers electric cars
Need new appliance standards, installation techniques and supporting technologies
Design & analysis tools to integrate components and predict whole-system energy performance
Test beds to assess new energy efficiency products
Minimum-load buildings technology pathway for emerging technologies and systems
DOE SunShot; NREL; ORNL; LBNL; PNNL
Technologies used to integrate and diagnose building controls in order to improve energy performance
NREL; Cornell; PNNL
Zero energy design process
NREL RSF; CEC PIER; PG&E "Architecture at Zero"
Testing of residential and commercial building systems
ORNL
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Technologies used to integrate and diagnose building controls in order to improve energy performance. Building controls can be used to improve building performance but often are unable to dynamically change with the changes in the building causing increase building's energy consumption.

Existing research: National Renewable Energy Laboratory (NREL), Cornell University, Pacific Northwest National Laboratory (PNNL).

- For NREL's research in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. What are the key operational failure points and how easy are they to fix? What technologies can fix these issues?
2. What other industries use diagnostics and how does that apply to building?
3. How can control be standardized to make installation easier?

Zero energy design process. Provide tools, education, case studies to improve the design process around energy efficiency and net zero energy.

Existing research: National Renewable Energy Laboratory (NREL) (including at the Research Support Facility (RSF)), California Energy Commission (CEC) Public Interest Energy Research (PIER) program, Pacific Gas & Electric (PG&E) "Architecture at Zero"

- NREL's RSF: http://www.nrel.gov/sustainable_nrel/rsf.html.
- For other NREL research in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. Understand how the design decisions are made.
2. Identify how to shift the decision process toward energy-driven design.
3. Identify how to incorporate building science in the design process.
4. Identify how to make design teams more interdisciplinary rather than just multidisciplinary.
5. Understand how the procurement process can drive performance based design.

Testing of residential and commercial building systems. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL).

- For ORNL's research in this area, see Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Continued . . .

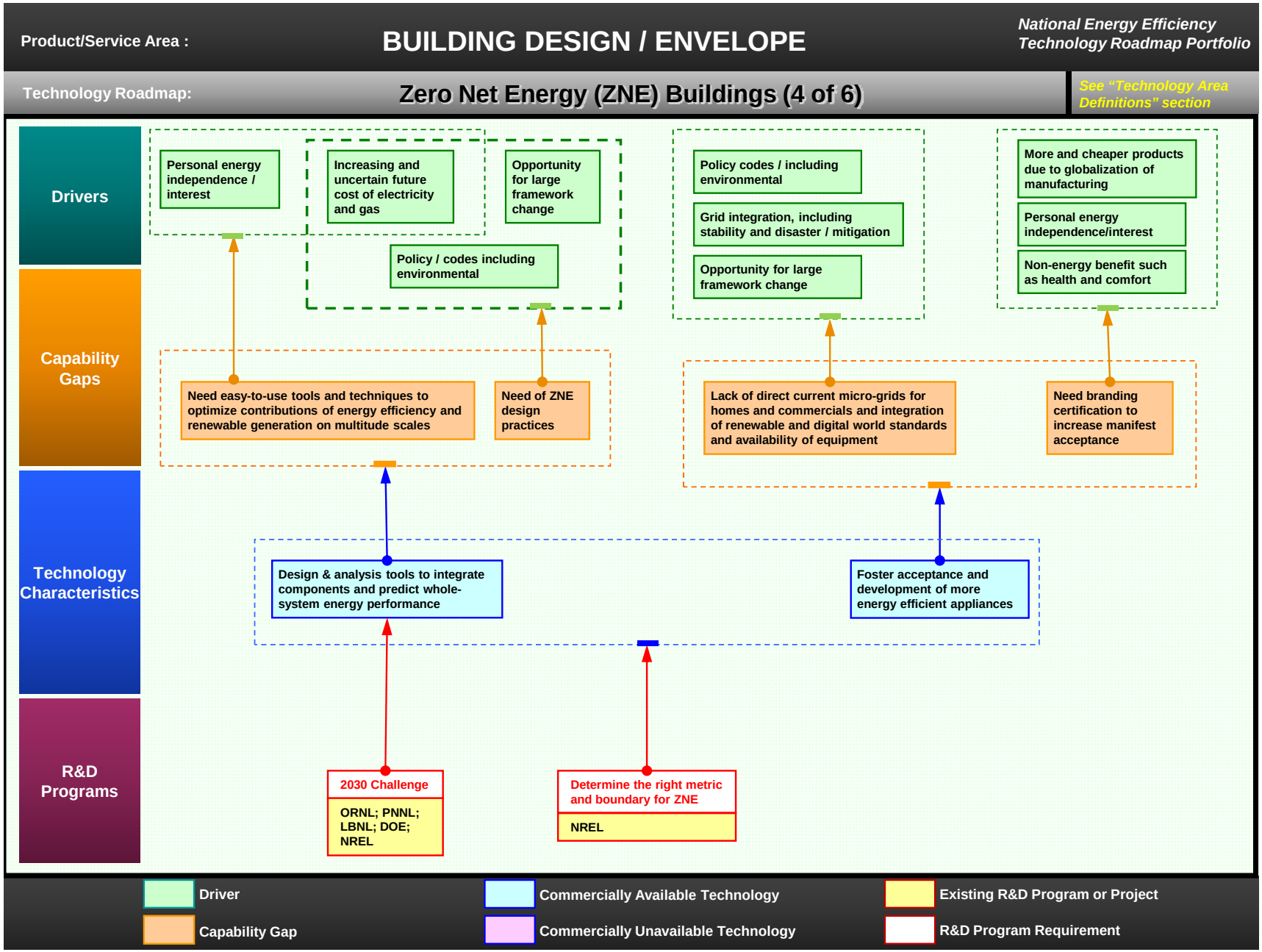
Minimum-load buildings technology pathway for emerging technologies and systems. To achieve carbon-neutrality by 2030 requires buildings, which contribute almost 50 percent of greenhouse gas emissions, to be designed to 50 percent of current average energy use for the building type and region at a cost competitive to grid supplied electricity.

Existing research: National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL), Pacific Northwest National Laboratory (PNNL), Department of Energy (DOE) Sunshot Initiative.

- NREL has developed two tools to facilitate building design and analysis to help reach these goals:
  - In My Backyard (IMBY) system estimates PV electricity production based on such factors as location and system size. The IMBY system uses a Google Maps interface to allow users to easily choose a system location with pinpoint accuracy (http://www.nrel.gov/eis/imby/).
  - The HOMER computer model simplifies design option evaluations for both off-grid and grid-connected remote, standalone, or distributed generation (DG) power systems (https://analysis.nrel.gov/homer/, http://www.homerenergy.com/).
- For ORNL research in this area, see Appendix B.
- In addition to the ongoing research & development projects at LBNL outlined in more detail in Appendix B, the LBNL is also working with the California Energy Commission and the Department of Energy to evaluate and improve tools for tracking and monitoring energy use in commercial buildings; see available tools at http://eis.lbl.gov/.
- PNNL research in this area is likely being done through the lab's Electricity Infrastructure & Buildings Division; as of Feb. 2012, specific projects had not been identified. See http://energyenvironment.pnnl.gov/ie_b_div.asp for more information.
- For DOE research in this area, see Appendix B.

Key research questions:

1. What are the system performance gaps that limit achievement of 50% goal?
2. What are the most cost effective system solutions to fill these gaps?
3. What incentive and performance improvement are required to fill gaps?
4. What is critical path at R&D plan and gates to deliver cost effective solutions?


Product/Service Area :
BUILDING DESIGN / ENVELOPE
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Zero Net Energy (ZNE) Buildings (4 of 6)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Personal energy independence / interest
Increasing and uncertain future cost of electricity and gas
Opportunity for large framework change
Policy / codes including environmental
Policy codes / including environmental
Grid integration, including stability and disaster / mitigation
Opportunity for large framework change
More and cheaper products due to globalization of manufacturing
Personal energy independence/interest
Non-energy benefit such as health and comfort
Need easy-to-use tools and techniques to optimize contributions of energy efficiency and renewable generation on multitude scales
Need of ZNE design practices
Lack of direct current micro-grids for homes and commercials and integration of renewable and digital world standards and availability of equipment
Need branding certification to increase manifest acceptance
Design & analysis tools to integrate components and predict whole-system energy performance
Foster acceptance and development of more energy efficient appliances
2030 Challenge
ORNL; PNNL; LBNL; DOE; NREL
Determine the right metric and boundary for ZNE
NREL
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Determine the right metric and boundary for ZNE. The effort is to determine the consistent definition of ZNE, ZNE source, on site, on ZNC and to find value proposition to the utility serving ZNE building.

Existing research: National Renewable Energy Laboratory (NREL)

- *[Summaries of existing research pending]*

Key research questions:

1. Document case studies that are success and not.
2. Analyze utility models for revenue and profits.
3. Monitor energy use in building that are designed for ZNE.
4. Construct one new ZNE building in areas not served by ZNE (e.g., pacific NW) and monitor the energy saving and peak load savings, if any.
5. Analyze impact on grid if large number of ZNE building are realized.

2030 Challenge. To achieve carbon-neutrality by 2030 requires buildings, which contribute almost 50 percent of greenhouse gas emissions, to be designed to 50 percent of current average energy use for the building type and region..

Existing research: National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL), Lawrence Berkeley National Laboratory (LBNL), Pacific Northwest National Laboratory (PNNL), Department of Energy (DOE) Sunshot Initiative.

- NREL has developed two tools to facilitate building design and analysis to help reach these goals:
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- For ORNL research in this area, see Appendix B.
- In addition to the ongoing research & development projects at LBNL outlined in more detail in Appendix B, the LBNL is also working with the California Energy Commission and the Department of Energy to evaluate and improve tools for tracking and monitoring energy use in commercial buildings; see available tools at http://eis.lbl.gov/.
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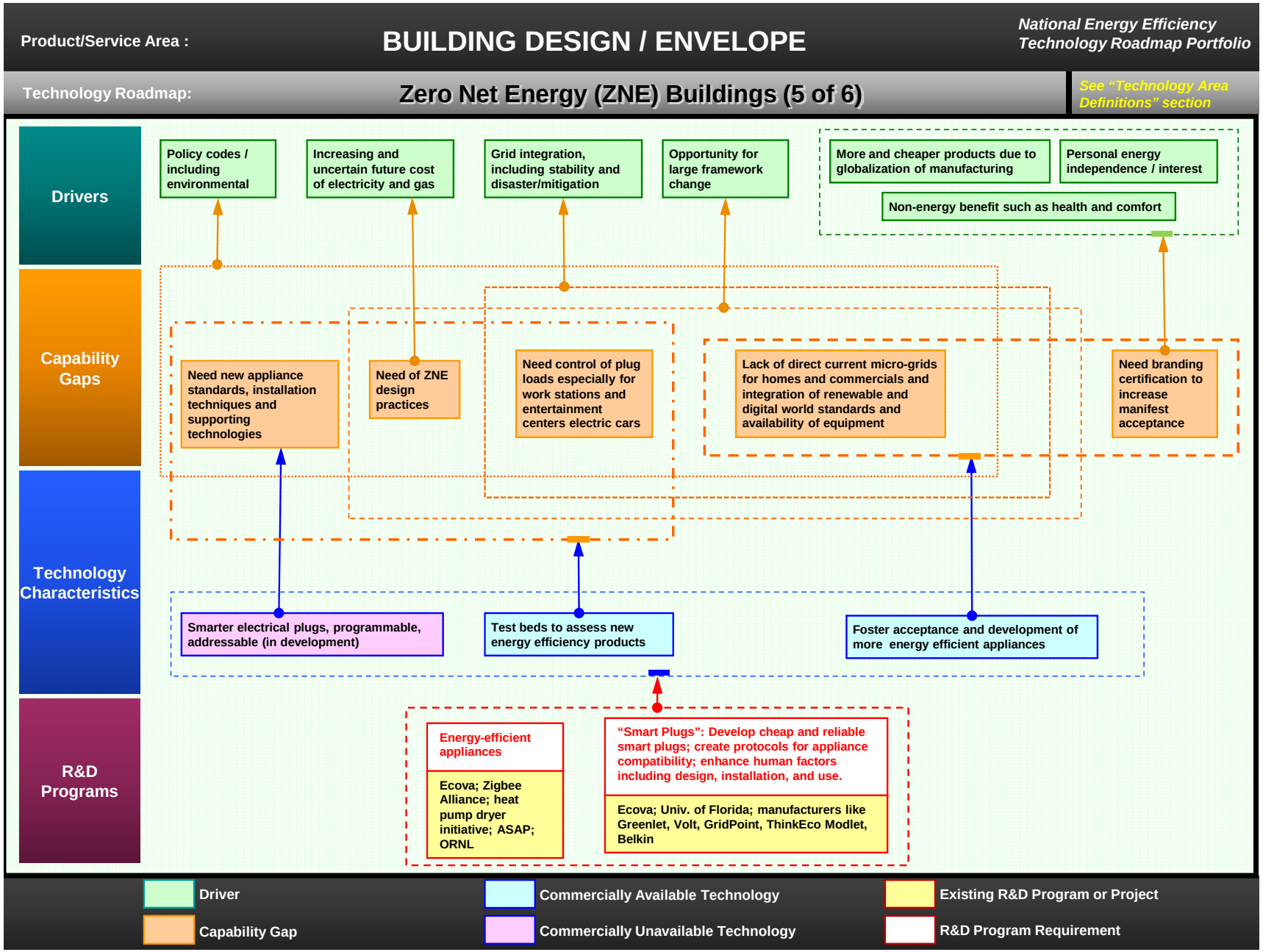
- For DOE research in this area, see Appendix B.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
BUILDING DESIGN / ENVELOPE
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Zero Net Energy (ZNE) Buildings (5 of 6)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Policy codes / including environmental
Increasing and uncertain future cost of electricity and gas
Grid integration, including stability and disaster/mitigation
Opportunity for large framework change
More and cheaper products due to globalization of manufacturing
Personal energy independence / interest
Non-energy benefit such as health and comfort
Need new appliance standards, installation techniques and supporting technologies
Need of ZNE design practices
Need control of plug loads especially for work stations and entertainment centers electric cars
Lack of direct current micro-grids for homes and commercials and integration of renewable and digital world standards and availability of equipment
Need branding certification to increase manifest acceptance
Smarter electrical plugs, programmable, addressable (in development)
Test beds to assess new energy efficiency products
Foster acceptance and development of more energy efficient appliances
Energy-efficient appliances
Ecova; Zigbee Alliance; heat pump dryer initiative; ASAP; ORNL
"Smart Plugs": Develop cheap and reliable smart plugs; create protocols for appliance compatibility; enhance human factors including design, installation, and use.
Ecova; Univ. of Florida; manufacturers like Greenlet, Volt, GridPoint, ThinkEco Modlet, Belkin
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

"Smart Plugs": Develop cheap and reliable smart plugs; create protocols for appliance compatibility; enhance human factors including design, installation, and use. Make smart outlets a standard feature in new construction requires innovation in technology and building industry practices. "Smart plugs" or "smart strips" can refer to the ability of the outlet to turn-off devices when they are not being used, and to interactivity with smart grid systems for demand response and load control. Research is needed primarily to develop the ability of plugs to turn off equipment when not in use; secondarily, to enable participation in demand response events.

Existing research: Ecova, University of Florida, and manufacturers like Greenlet, Volt, GridPoint, ThinkEco, Modlet, and Belkin.

- Ecova(http://www.ecova.com/) has done research on the energy savings potential of plugs that turn off devices when that are not being used. Their efforts have led them to identify the same technology gap that Pacific Northwest regional stakeholders have: further research is needed on the linkage of smart strips to building control interfaces (such as ZigBee, http://www.zigbee.org/). Research in this area would incorporate the functionality of both types of "smart plugs" (see Ecos Consulting, "Smart Plug Strips: Draft Report," July 22, 2009, http://www.efficientproducts.org//reports/smartplugstrip/Ecos-Smart-Plug-Strips-DRAFT-Jul2009-v2x.pdf).
- Researchers in the University of Florida's Computer and Information Science and Engineering Department (http://www.cise.ufl.edu/) have conducted some research on smart plugs and smart environments that addresses plug design, capabilities, and installation. This research explores the ability of the home operating system, but does not address smart grid integration for demand response purposes (see Hicham Elzabadani, Abdelsalam (Sumi) Helal, Bessam Abdulrazak, and Erwin Jansen, "Self-Sensing Spaces: Smart Plugs For Smart Environments," 2005, http://www.icta.ufl.edu/projects/publications/2005-ICOST-Selfsensingspaces.pdf).
- *[Summaries of other existing research pending]*

Key research questions:

1. Eliminate stand by losses.
2. Power conversion efficiency.
3. Hand wired devices.
4. Transition technologies (no demand for DC if there are only AC grid)

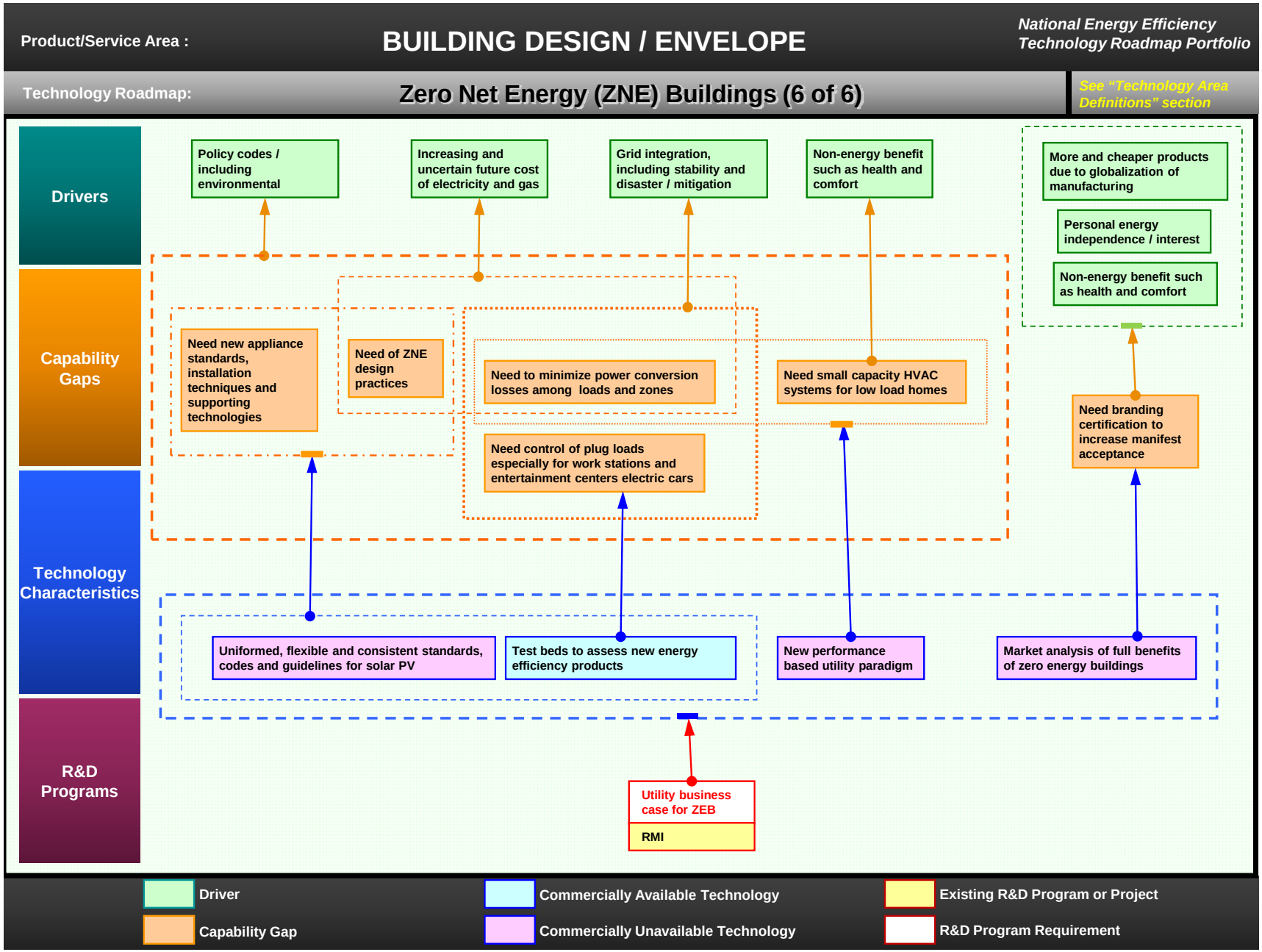
Energy-efficient appliances. Create a new generation of appliances that are equipped for the quid of the future including DC power, load shedding, etc.

Existing research: Oak Ridge National Laboratory (ORNL), Department of Energy (DOE), Ecova, Zigbee, the Alliance to Save Energy (ASE) Appliance Standards Awareness Project (ASAP), and "heat pump water initiative.".

- ASE ASAP: http://ase.org/programs/appliance-standards-awareness-project.
- For ORNL research in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. What is the best optimal efficiency for each appliance and what would it take to move the technology in that direction?
2. Can appliances be designed for DC loads?
3. What appliances can be designed to operate off peak and the methods to make this happen.


Product/Service Area :
BUILDING DESIGN / ENVELOPE
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Zero Net Energy (ZNE) Buildings (6 of 6)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Policy codes / including environmental
Increasing and uncertain future cost of electricity and gas
Grid integration, including stability and disaster / mitigation
Non-energy benefit such as health and comfort
More and cheaper products due to globalization of manufacturing
Personal energy independence / interest
Non-energy benefit such as health and comfort
Need new appliance standards, installation techniques and supporting technologies
Need of ZNE design practices
Need to minimize power conversion losses among loads and zones
Need small capacity HVAC systems for low load homes
Need branding certification to increase manifest acceptance
Need control of plug loads especially for work stations and entertainment centers electric cars
Uniformed, flexible and consistent standards, codes and guidelines for solar PV
Test beds to assess new energy efficiency products
New performance based utility paradigm
Market analysis of full benefits of zero energy buildings
Utility business case for ZEB
RMI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Utility business case for ZEB. Validate commercial scale, operating characteristics and business cases for ZEB.

Existing research: Rocky Mountain Institute (RMI).

- *[Summaries of existing research pending]*

Key research questions:

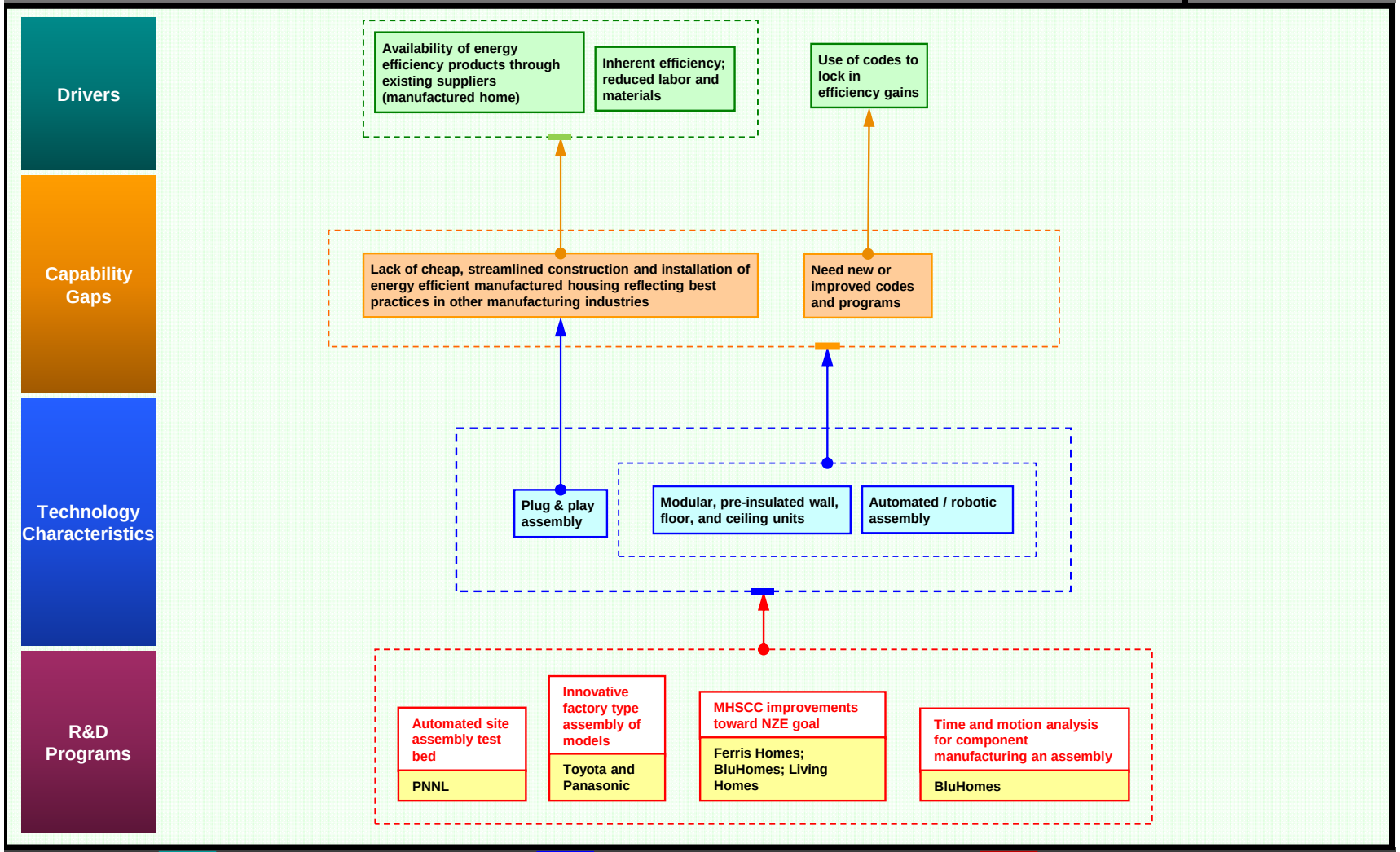
1. What are the values of peak reduction, grid stability, grid efficiency?
2. What is true service cost for utility to service ZEB (infrastructure, delivery)?
3. How do ZEB mitigate the risks?
4. How can this all come together to support a new business case for utilities?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Manufactured Housing / Modular / Pre Manufactured Systems / Offices**

See "Technology Area Definitions" section



Driver | Commercially Available Technology | Existing R&D Program or Project

Capability Gap | Commercially Unavailable Technology | R&D Program Requirement

R&D Program Summaries

Innovative factory type assembly of models. Modular buildings are generally overlooked. Significant energy efficiency, cost savings and financial benefits are achievable. Optimization is possible by adopting techniques from other high through-put industries.

Existing research: Most of the work done to date in this area has been in Japan under the leadership of Panasonic and Toyota. Based upon available data, while Panasonic and Toyota do appear to be producing advanced manufactured housing that deliver significant energy efficiency results, it is not clear the extent to which the work in Japan involves innovative shop floor technologies. Further, it does not appear that much is being done to bring these technologies to the U.S. housing industry. Therefore, further domestic research in this area seems warranted.

- Panasonic: http://www.panahome.jp/english/.
- Toyota: http://www.toyota-global.com/company/profile/non_automotive_business/housing.html; see also Appendix B.

Key research questions:

1. What approached from other assembly industries can be adopted by the modular building industry?
2. What are the experiences in other countries (Japan, Europe)?
3. What are the key requirements?
4. Are there novel material types of construction that can be easily adapted to modular buildings (phase change materials, DC power)?
5. Where are the costs that can be removed and yet maintain efficiency?

Automated site assembly test bed. Accelerate development of new low labor cost, automated site assembly techniques for production construction of low load, zeb-ready, buildings.

Existing research: Pacific Northwest National Laboratory (PNNL).

- *[Summaries of existing research pending]*

Key research questions:

1. What are the best approaches for automated attachment of cladding systems over 1" exterior insulating sheathing?
2. What are quick ways to convert conventional panelizers of high R walls into producers?
3. What are the specific markets and business cases for automated site assembly systems that improve quality and reduce labor costs?
4. Validate incremental benefits in red test bed

Time and motion analysis for component manufacturing an assembly. Find opportunities for cost reduction. Innovation by analyzing existing manufacturing and assembly of energy related products to determine opportunities for improvement.

Existing research: BluHomes.

- *[Summaries of existing research pending]*

Key research questions:

1. Not yet identified.

Continued . . .

MHSCC improvements towards the NZE goal. Federal Housing and Urban Development (HUD) code homes pre-empt state energy codes and use Manufactured Home Construction and Safety Standards (MHCSS) for mechanical systems, lighting, HVAC + energy. The requirements in the current code limit innovative emerging technology market transformation.

Existing research: Ferris Homes, BluHomes, Living Homes.

- *[Summaries of existing research pending]*

Key research questions:

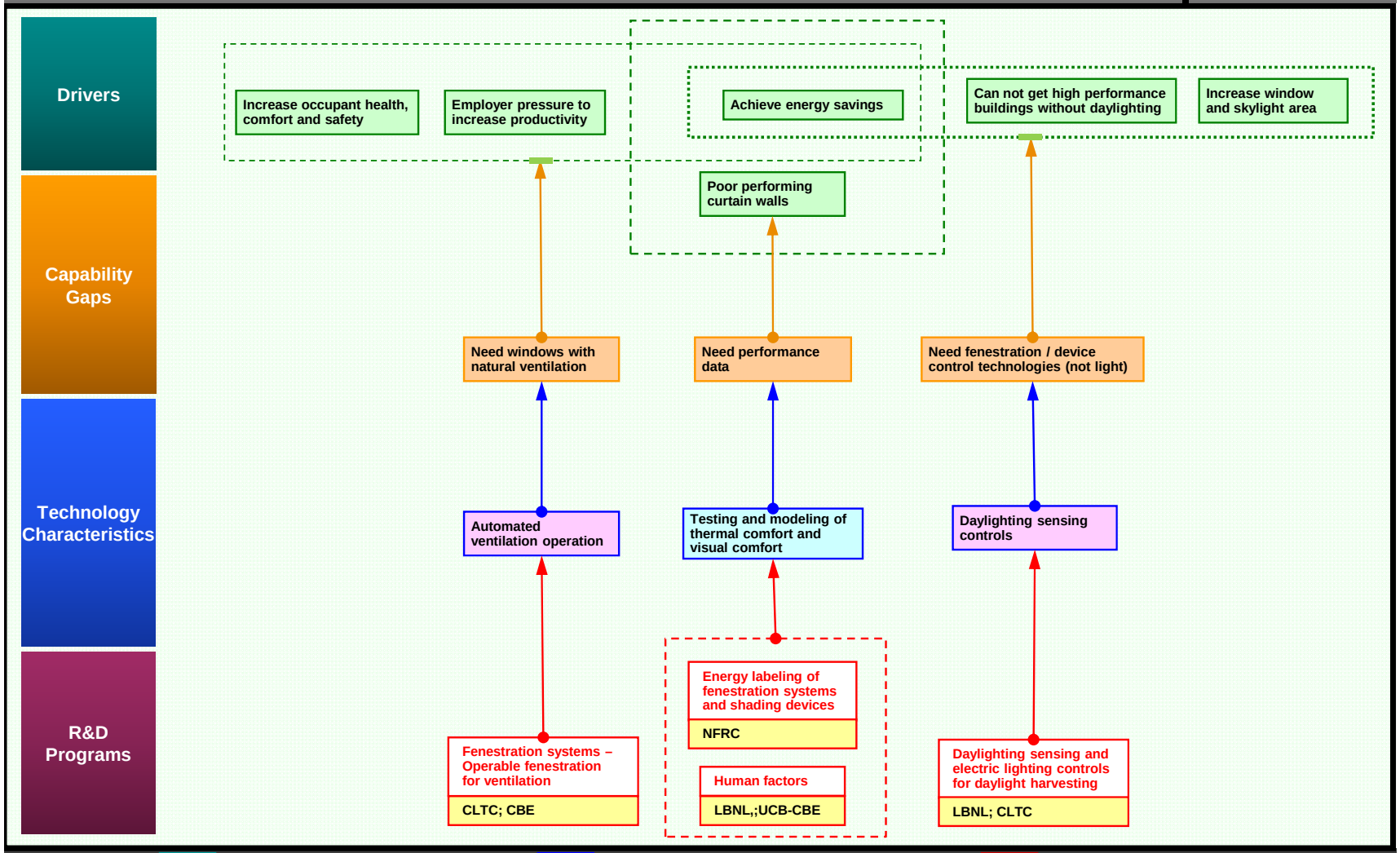
1. What MHCSS code requirements need to change to facilitate ET adoption?
2. How do we improve design, installation, QA and set-up process to address ET requirements?
3. What building science QA tools should be added to MH QA in place + on-site requirements?
4. What are the additional costs of ET as "special / order" ?
5. What codes and standards should MHCSS be looking to for reference, guidance?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (1 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Fenestration systems – Operable fenestration for ventilation. Develop fenestration systems with natural ventilation capabilities that can be activated manually and/or automatically based on occupant needs and/or HVAC operation. This can be done through operation of sash components or through dedicated vent mechanisms in window/skylight frames.

Existing research: University of California Davis California Lighting Technology Center (CLTC), University of California Berkeley Center for the Built Environment (CBE).

- *[Summaries of existing research pending]*

Key research questions:

1. How do we develop improved sash components for automated operation and easier manual operation?
2. How do we develop vent mechanisms with actuators for manual and automated operation?
3. How do we develop control algorithms for automated operation based on HVAC status, loads, and occupant needs?

Human factors. Investigate effects of daylighting and thermal comfort on humans. Examine and determine physiological and psychological effects of daylighting and thermal comfort. Examine occupant acceptance of controls (fenestration or integrated) and investigate improved interfaces.

Existing research: Lawrence Berkeley National Laboratory (LBNL), University of California Berkeley Center for the Built Environment (CBE).

- *[Summaries of existing research pending]*

Key research questions:

1. Investigate physiological effects of daylighting (circadian rhythm, relaxation of the eye, vitamin, etc.)
2. Psychological effects of daylighting and visual transmittance (view, effects of enlarged spaces, etc.)
3. Develop better thermal comfort indices that take into account radiant asymmetry, physiology of humans.
4. Develop improved user interfaces to fenestration and integrated controls.

Daylighting sensing and electric lighting controls for daylight harvesting. Develop alternative ways of sensing daylight and adjusting electric lighting output accordingly for window and skylight applications.

Existing research: Lawrence Berkeley National Laboratory (LBNL), University of California Davis California Lighting Technology Center (CLTC).

- *[Summaries of existing research pending]*

Key research questions:

1. How do we develop improved daylight sensing in terms of reliability and cost?
2. How do we develop algorithms with automatic calibration and occupant adjustment capabilities?
3. How do we develop integrated approaches that use multiple sensors or sensor networks for improve daylight sensing and integrated operation and lighting and HVAC controls.

Energy labeling of fenestration systems and shading devices. Develop more informative and easier to understand energy labels for fenestration systems and shading devices. Include both fundamental indices of performance (U-factor, SHGT, VT, AL) and annual energy use. Express performance in easy understand manner.

Existing research: National Fenestration Rating Council (NFRC).

- *[Summaries of existing research pending]*

Key research questions:

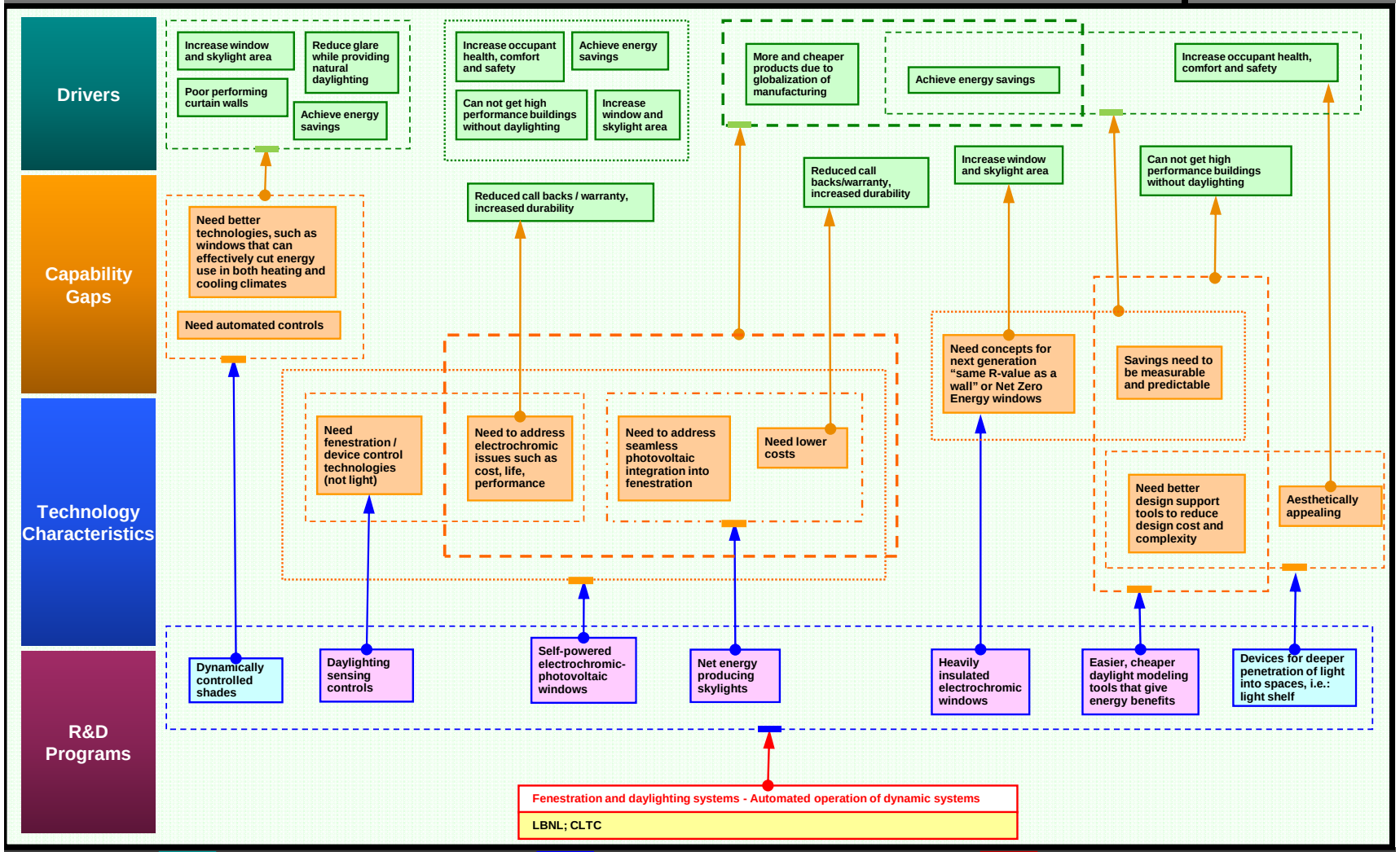
1. Develop basic performance indices for shading devices and other window attachments that would express their performance but be different from windows.
2. Establish rating and certification system for window attachments, shading devices.

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (2 of 8)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Fenestration and daylighting systems – Automated operation of dynamic systems.

How to automate the operation of dynamic glazing and shading systems, based on environmental conditions, such as illumination, temperature, occupancy, etc. to improve comfort and reduce energy requirements. Automated operation could/should include integration with electric lighting and HVAC systems, while providing occupant overriding capabilities.

Existing research: Lawrence Berkeley National Laboratory (LBNL), University of California Davis California Lighting Technology Center (CLTC).

- *[Summaries of existing research pending]*

Key research questions:

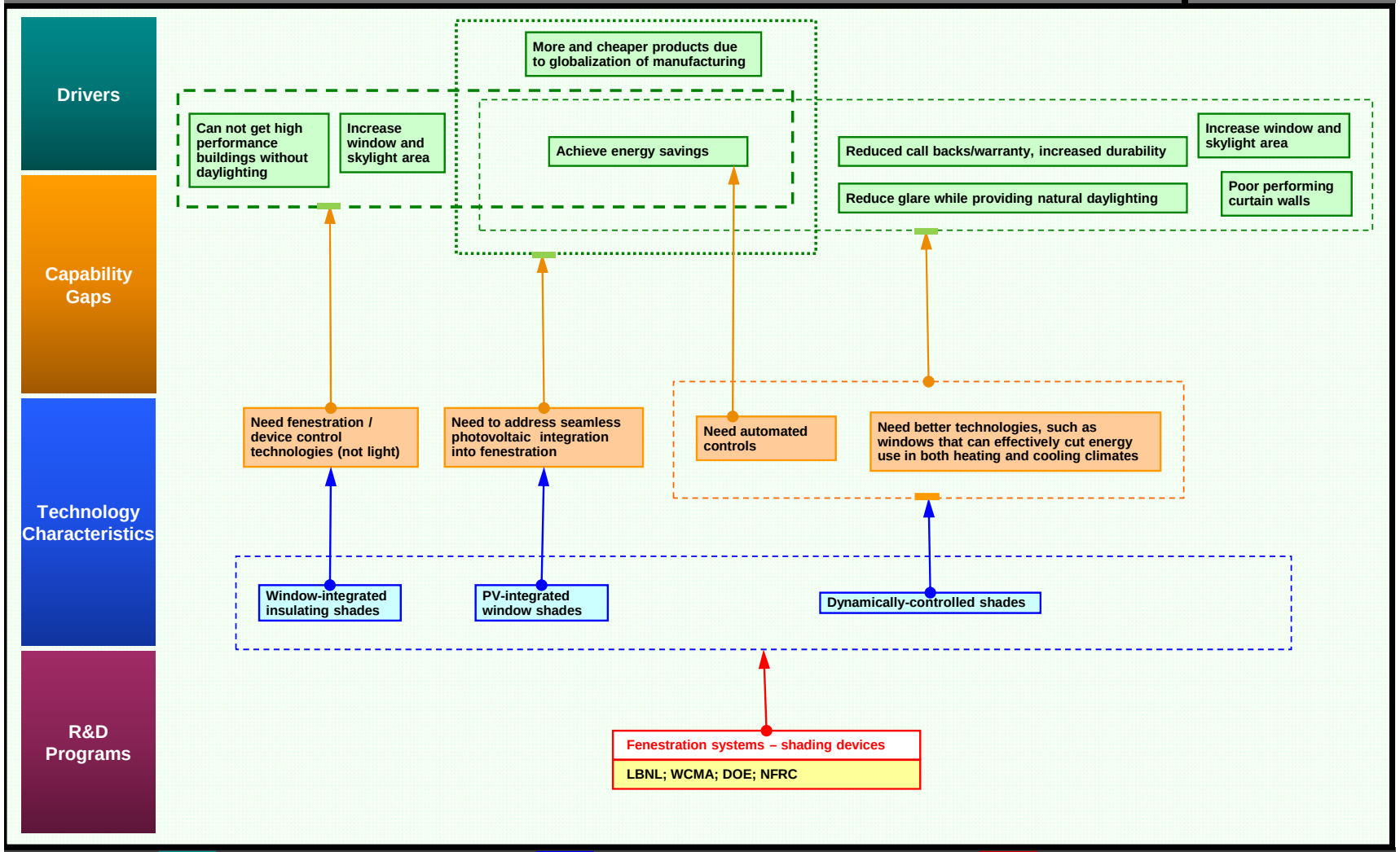
1. How do we develop improved environmental sensing capabilities, such as light, heat, relative humidity, occupancy with individual and/or sensor networks?
2. How do we develop control algorithms that take as input signals from sensors and activate actuators to adjust dynamic components of fenestration systems?
3. How do we develop fault detection and diagnostics to identify and correct fault operations?
4. How do we develop control algorithms for integrated fenestration, lighting and HVAC operation?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (3 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

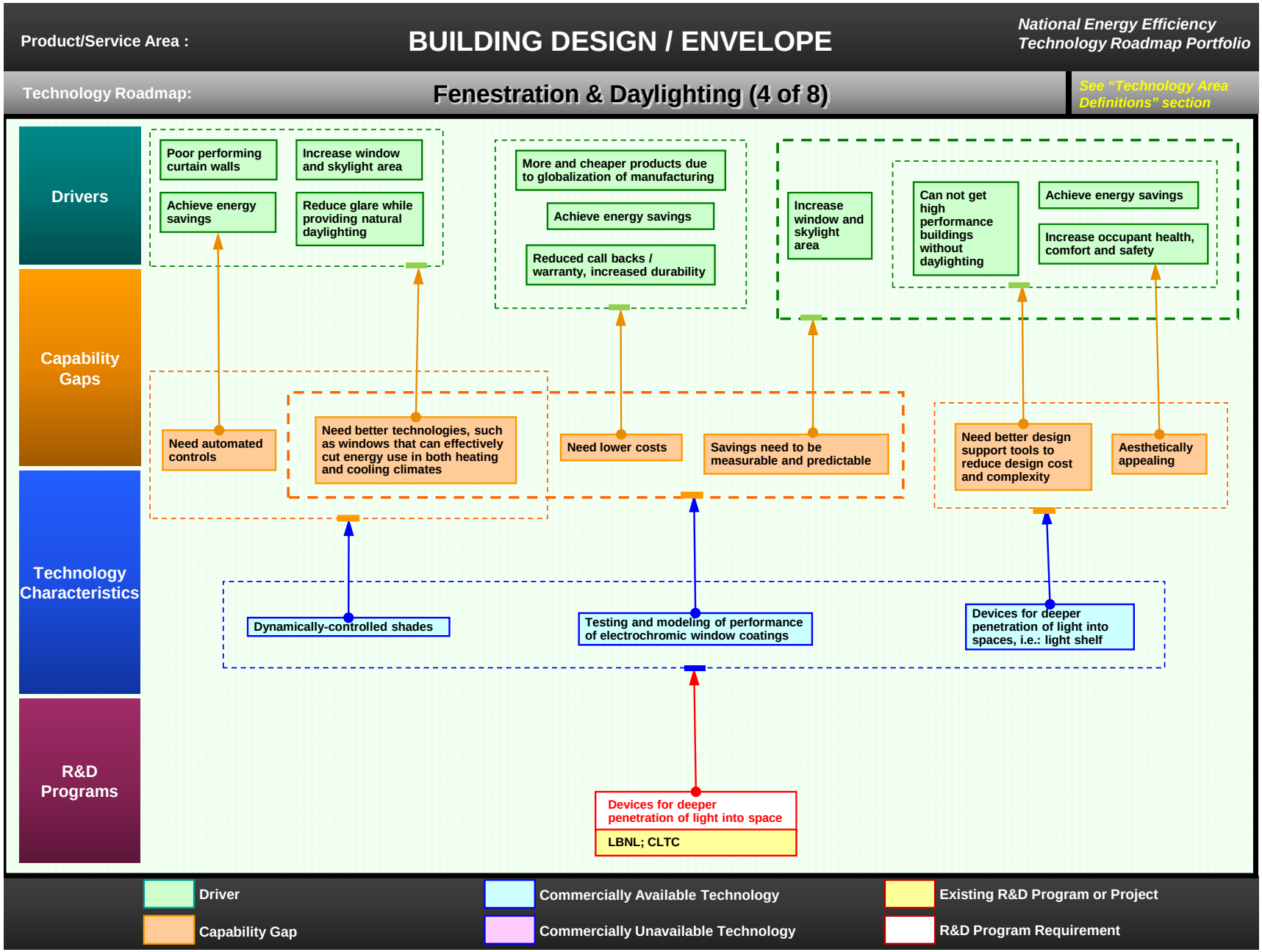
Fenestration systems – shading devices. Develop shading systems to control direct solar penetration in interior spaces, also aiming at reduced glare and heat transfer. Those can be static or dynamic. The later can be manually and/or automatically operated.

Existing research: Lawrence Berkeley National Laboratory (LBNL), (WCMA), Department of Energy (DOE), National Fenestration Rating Council (NFRC).

- DOE: Subject matter experts indicated September 2012:"forthcoming funds for attachment ratings."
- NFRC: Subject matter experts indicated September 2012:"storm doors."
- *[Summaries of other existing research pending]*

Key research questions:

1. How do we develop the next generation of external shading systems, such as overhangs, horizontal and/or vertical louvers, awnings, etc?
2. How do we develop insulated shutters (rolling, sliding, swing, etc) either stand-alone or integrated with window systems?
3. How do we develop between glazing panel shades, such as blinds, solar screens, films, perforated shades, etc?
4. How do we develop interior shades, such as blinds, solar screen films, perforated shades, insulated shades, such as cellular shades and window quilts?
5. How do we develop exterior or interior shading systems with integrated PV?


Product/Service Area :
BUILDING DESIGN / ENVELOPE
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Fenestration & Daylighting (4 of 8)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Poor performing curtain walls
Increase window and skylight area
Achieve energy savings
Reduce glare while providing natural daylighting
More and cheaper products due to globalization of manufacturing
Achieve energy savings
Reduced call backs / warranty, increased durability
Increase window and skylight area
Can not get high performance buildings without daylighting
Achieve energy savings
Increase occupant health, comfort and safety
Need automated controls
Need better technologies, such as windows that can effectively cut energy use in both heating and cooling climates
Need lower costs
Savings need to be measurable and predictable
Need better design support tools to reduce design cost and complexity
Aesthetically appealing
Dynamically-controlled shades
Testing and modeling of performance of electrochromic window coatings
Devices for deeper penetration of light into spaces, i.e.: light shelf
Devices for deeper penetration of light into space
LBNL; CLTC
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Devices for deeper penetration of light into space. Develop new generation of coating and surface-applied films that allow for light redirection for deeper penetration of light into space. Develop improved devices for bringing light into the core space that cannot be served by light redirecting systems.

Existing research: Ongoing research in this area includes work at the California Lighting Technology Center (CLTC) at the University of California Davis (in partnership with the University of British Columbia (UBC)) and the Lawrence Berkeley National Laboratory (LBNL).

- UBC Structured Surface Physics Department (http://www.phas.ubc.ca/ssp/index.html) developed and extensively evaluated their Core Sunlighting System (http://www.phas.ubc.ca/ssp/CoreSun_index.html), a cost-effective, architecturally-integrated approach that they call "the first core daylighting system with potential for widespread adoption." The system is composed of sunlight concentration panels and dual-function prism light guides to replace conventional light fixtures and incorporate lighting fixture dimming technologies to distribute collected sunlight. As of early 2012, SunCentral Inc. (http://www.suncentralinc.com/) is developing this technology for commercial applications, with a projected market availability date of 2013.
- The CLTC is currently working on an R&D project to evaluate the application of UBC's Core Sunlighting System to the climate and topography of California's Central Valley. See Appendix B for more information on this effort.
- LBNL's Windows & Daylighting team in the Buildings Energy Efficiency research group has developed some daylighting technologies and strategies over the past two decades, including lightshelves / lightpipes, tools for daylighting predictions, and daylighting controls. (http://windows.lbl.gov/daylighting/Default.htm). As of Feb. 2012, it is not clear what specific R&D projects in these areas are ongoing at LBNL.

Key research questions:

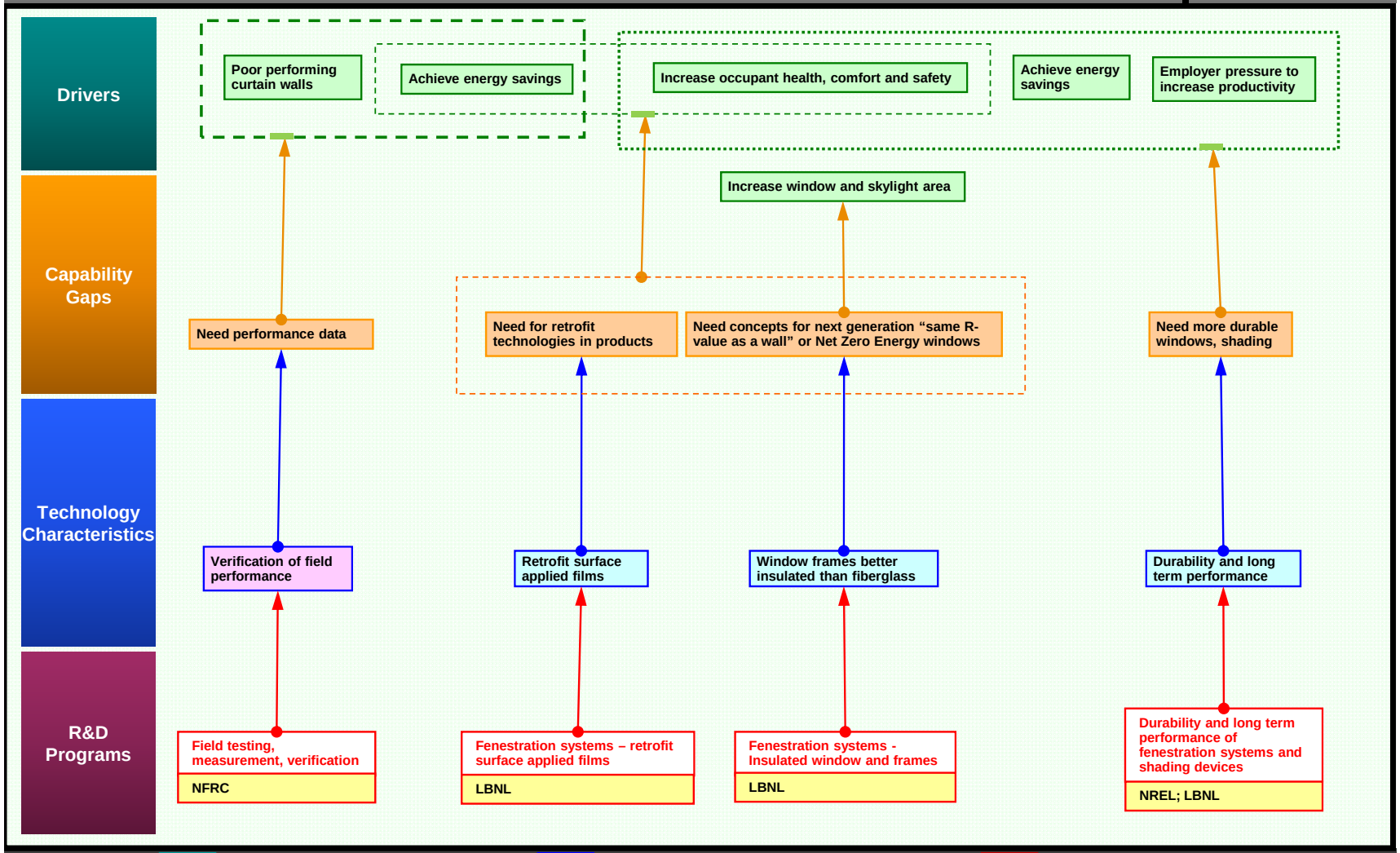
1. How do we develop light redirecting glazing and glazing coatings, such as prismatic glazing?
2. How do we develop light redirecting films, such as holographic?
3. How do we develop devices that redirect lights, such as light shelves, blinds, louvers, etc?
4. How do we develop devices that direct daylighting into core spaces, such as active tubular daylighting devices, light concentrators, and transport systems (e.g. fiberoptics)?
5. How do we develop integration of daylighting devices with electric lighting systems?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (5 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Fenestration systems – retrofit surface applied films. Develop retrofit surface applied films that improve the overall proprieties of glazing systems, such as condensation resistance (CR), solar heat gain coefficient (SHGC), and U-factor.

Existing research: Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Electrochromics, including integration with PV for elimination of wiring.
2. Switchable photochronics, including integration with PV for eliminating of wiring.
3. Passive photochronics.
4. Passive electrochromics.
5. Liquid crystal display (LCD) coatings.
6. Low-e surface applied films.

Fenestration systems - Insulated window and frames. Develop windows frames that include lightweight insulating materials, such as aerogels, insulating foams and thermal breaks to improve the overall thermal performance of windows and skylight systems.

Existing research: Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

1. How do we develop thermal breaks for commercial framing, which is usually made of aluminum alloys that increase thermal resistance while preserving structural integrity?
2. How do we develop insulated foams and aerogels and their placement in frames so that they do not impede operation and are cost effective?
3. How do we develop hardware that does not introduce additional thermal bridging?
4. How do we develop low-e coating to minimize radiation heat transfer for increase insulation?

Durability and long term performance of fenestration systems and shading devices. Tighten and improve durability standards and measurements methods to asses durability of insulated glazing units, whole fenestration products and shading systems and attachments and their interaction.

Existing research: National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Develop better sealants and processes to improve IGU durability and long term performance.
2. Develop new generation of durability assessment standards and measurement methods.
3. Investigate potential negative interaction between windows and shading devices.
4. Investigate glazing deflective and its negative impacts on energy performance and surrounding structures (e.g. solar radiation focusing).

Continued . . .

Field testing, measurement, verification. Develop laboratory and field testing protocols and standards to reduce variability in reported results. Harmonize standards with the International Organization for Standardization (ISO) to involve international research and testing organizations. Develop replicable verification protocol for simulation/modeling results. Develop equipment for field measurements of daylighting and energy strategies and technologies.

Existing research: National Fenestration Rating Council (NRFC).

- *[Summaries of existing research pending]*

Key research questions:

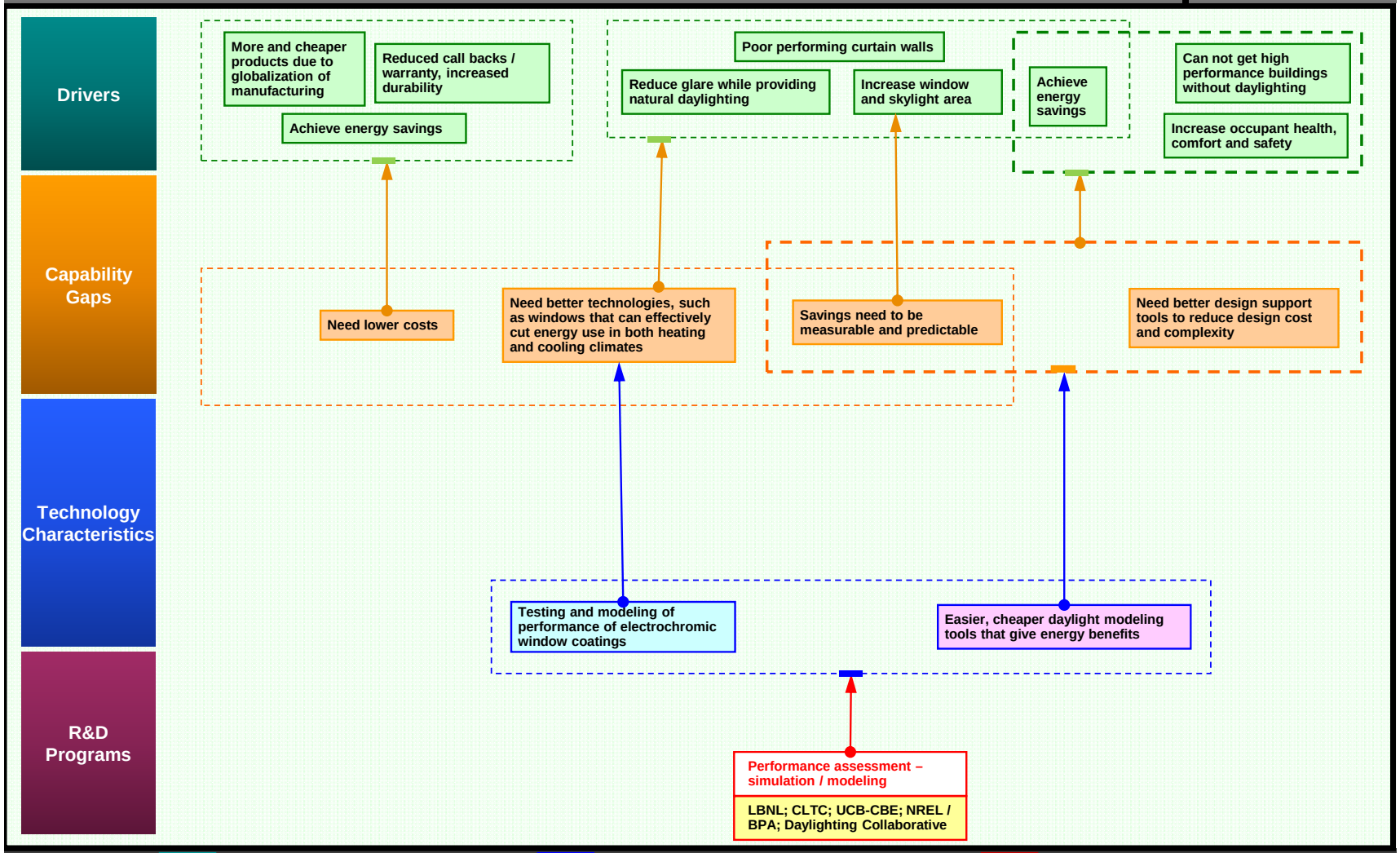
1. How do we develop field measurement protocol to verify daylight performance of fenestration systems and shading devices?
2. How do we develop field measurement protocol to verify energy performance of fenestration systems and shading devices?
3. How do we develop improved laboratory testing protocol for shading systems, addressing thermal, optical, and solar optical performance?
4. How do we develop measurement devices for improved sensing and monitoring?
5. How do we develop database of field testing and verification results, easily accessible?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (6 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Performance assessment – simulation / modeling. Develop improved algorithms, as well as missing algorithms for fenestration system performance assessment that includes daylighting, solar control, and thermal performance. Develop links to lighting and HVAC simulation for consideration of total building energy performance. **.** Affordable daylighting design and commissioning software with intuitive design features for ease of usability will assist in optimum placement of sensors and optimum daylight harvesting, promoting successful and long-lasting applications.

Existing research: Ongoing R&D at the following: Daylighting Collaborative; National Renewable Energy Laboratory (NREL), with Bonneville Power Administration (BPA); Lawrence Berkeley National Laboratory (LBNL); California Lighting Technology Center (CLTC); and the University of California Berkeley Center for the Built Environment (UCB-CBE).

- NREL is working on a project funded by the Bonneville Power Administration (BPA) Technology Innovation (TI) Office to study the feasibility of integrating building energy models for new and existing buildings that evaluates daylighting as a viable energy efficiency strategy and that can be analyzed using emerging building energy efficiency metrics such as the Energy Utilization Index (EUI). This is BPA TI Project #252,"Integrated Daylighting and Energy Analysis Toolkit (IDEAKit)"; See Appendix B for more information.
- Daylighting Collaborative: http://www.daylighting.org/.
- *[Summaries of other existing research pending]*

Key research questions:

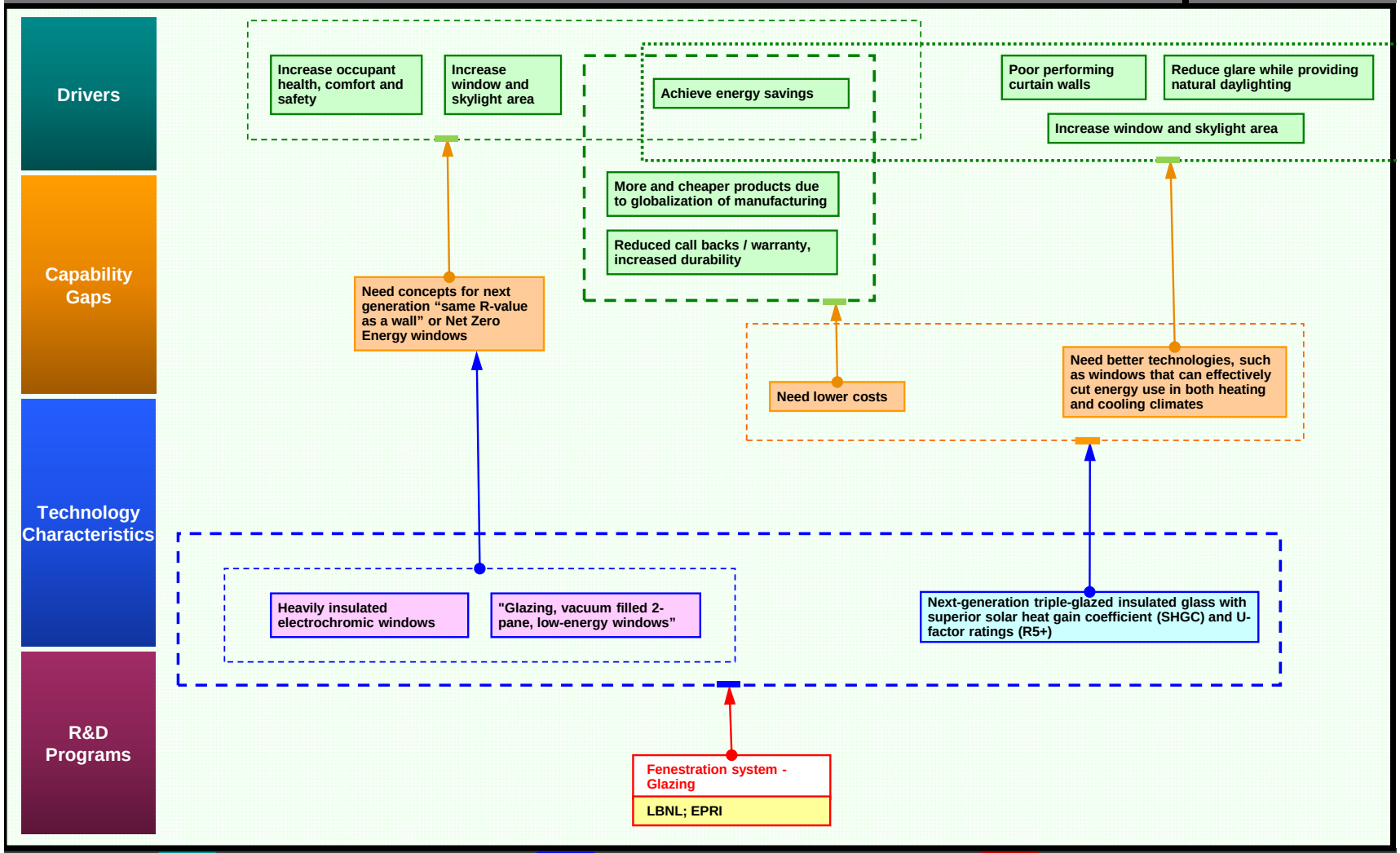
1. Develop optical modeling algorithms for arbitrary geometry of shading devices.
2. Develop improved algorithms for modeling air flow thermal effects shading devices (effects of porosity and openness on thermal performance.
3. Standardize formats and reporting of optical data for light scattering systems.
4. Develop more efficient algorithms in whole building energy simulation programs for complex fenestration systems.
5. Develop better models for daylighting spaces in buildings.
6. Develop harmonized modeling standards through activities within the International Organization for Standardization (ISO) .

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (7 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Fenestration system - Glazing. Develop dynamic insulated glazing systems for increased energy efficiency towards meeting the zero-net energy goal. These are insulated glazing that change their solar optical proprieties (visible transmittance (VT), solar heat gain coefficient (SHGC)) based on direct occupant control, or automated operation based on environmental factor affecting comfort and energy requirements.

Existing research: Lawrence Berkeley National Laboratory (LBNL), Electric Power Research Institute (EPRI).

- For EPRI's work in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

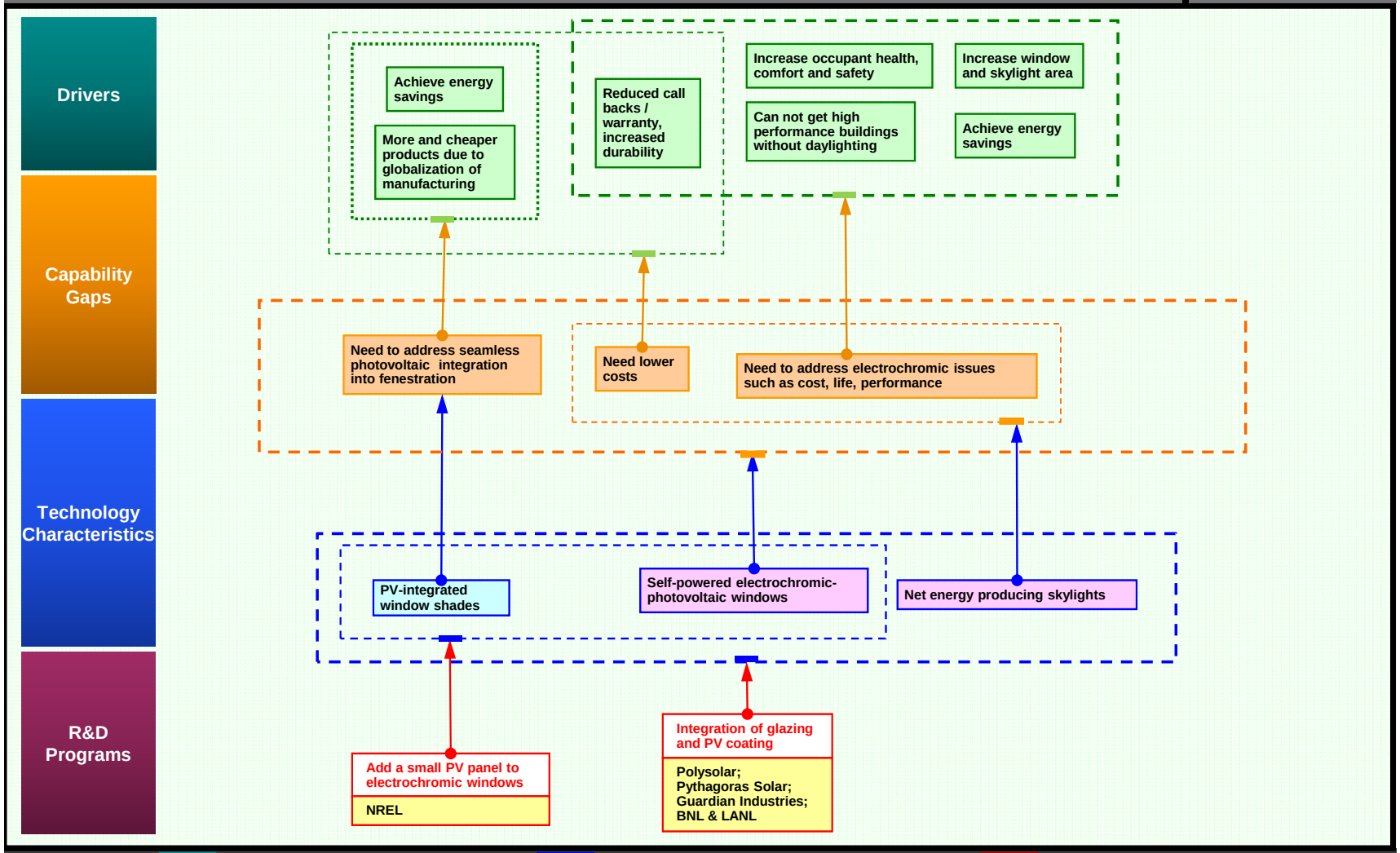
1. How do we develop more readily deployable highly insulating glazing (triple, quad, vacuum)?
2. How do we develop active chromogenic glazing (electrochromic)?
3. How do we develop passive chromogenic glazing (thermochromic, photochromic)?
4. How do we develop liquid crystal display (LCD) glazing?
5. How do we develop active (switchable) photo chromic glazing?

Product/Service Area : **BUILDING DESIGN / ENVELOPE**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fenestration & Daylighting (8 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Integration of glazing and PV coating. Develop photovoltaic (PV) coating systems that allow visible light to be transmitted and use the infrared (IR) component of solar radiation to produce electricity for the grid.

Existing research: Ongoing R&D at: Polysolar; Pythagoras Solar; Guardian Industries; and a collaborative project between Brookhaven National Laboratory (BNL) and Los Alamos National Laboratory (LANL).

- For BNL and LANL's work in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. Angle-optimized skylights and roof windows for photovoltaic (PV) penetration.
2. Reduce angle-dependency for photovoltaic (PV) integration in vertical glazing.

Add a small PV panel to electrochromic windows. Increase lighting proportionally or insulate during the cooling season.

Existing research: National Renewable Energy Laboratory (NREL).

- See Appendix B for more information on NREL's research into advanced prototypes for electrochromic windows.

Key research questions:

1. Questions not yet specified.

Lighting Roadmaps

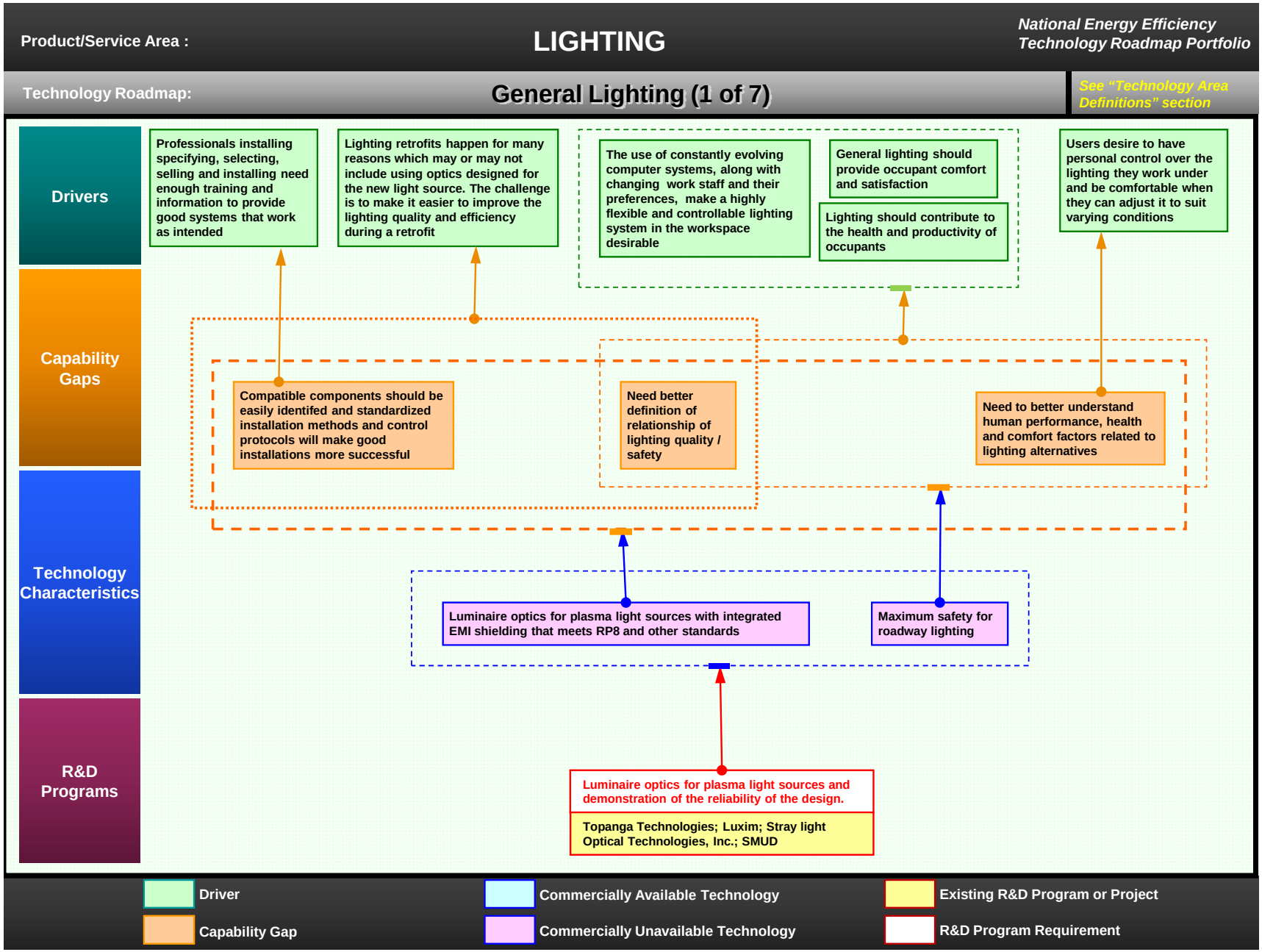
This section contains the following roadmaps:

- General Lighting
- Solid State Lighting
- Task/Ambient Lighting
- Lighting Controls
- Luminaires
- Daylighting

Other relevant sources

The list below is intended to be broadly representative rather than exhaustive and will be updated as new information becomes available.

U.S. Department of Energy Office of Energy Efficiency and Renewable Energy, *Solid-State Lighting Research and Development: Multi-Year Program Plan*, prepared by Bardsley Consulting (and others), April 2012, http://apps1.eere.energy.gov/buildings/publications/pdfs/ssl/ssl_mypp2012_web.pdf.


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
General Lighting (1 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Professionals installing specifying, selecting, selling and installing need enough training and information to provide good systems that work as intended
Lighting retrofits happen for many reasons which may or may not include using optics designed for the new light source. The challenge is to make it easier to improve the lighting quality and efficiency during a retrofit
The use of constantly evolving computer systems, along with changing work staff and their preferences, make a highly flexible and controllable lighting system in the workspace desirable
General lighting should provide occupant comfort and satisfaction
Lighting should contribute to the health and productivity of occupants
Users desire to have personal control over the lighting they work under and be comfortable when they can adjust it to suit varying conditions
Compatible components should be easily identifed and standardized installation methods and control protocols will make good installations more successful
Need better definition of relationship of lighting quality / safety
Need to better understand human performance, health and comfort factors related to lighting alternatives
Luminaire optics for plasma light sources with integrated EMI shielding that meets RP8 and other standards
Maximum safety for roadway lighting
Luminaire optics for plasma light sources and demonstration of the reliability of the design.
Topanga Technologies; Luxim; Stray light Optical Technologies, Inc.; SMUD
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

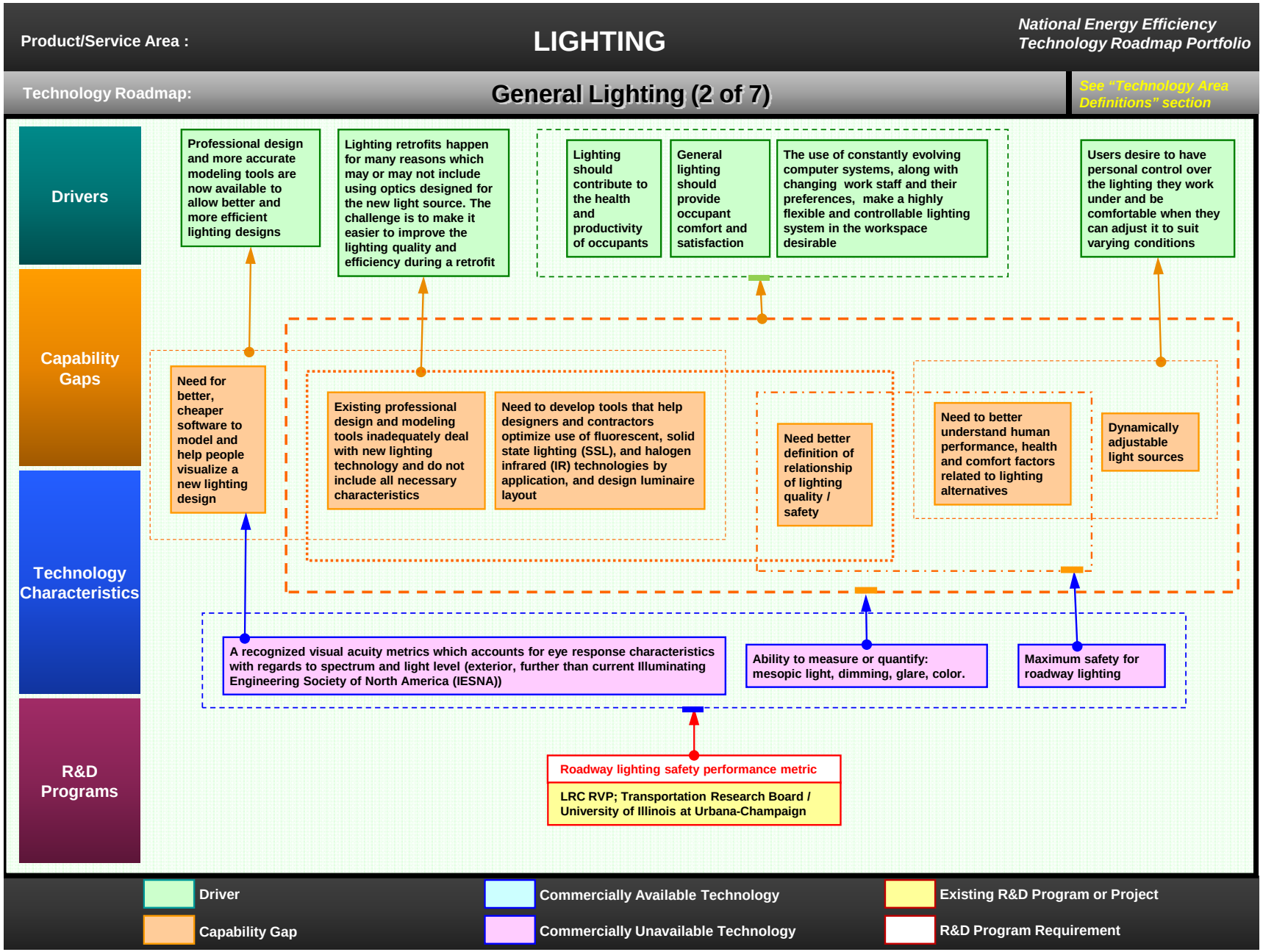
Luminaire optics for plasma light sources and demonstration of the reliability of the design. Plasma lighting claims 120+ lumen per watt and 50,000+ hours life. Research on better luminaire optics is needed. The demonstration of this technology into roadway, manufacturing, and low light applications needs to be documented and disseminated.

Existing research: California Lighting Technology Center (CLTC) affiliates Luxim Corporation and Topanga Technologies are two of the leading light-emitting plasma (LEP) companies. Another company doing research in this area is Stray light Optical Technologies, Inc., Sacramento Municipal Utility District (SMUD)

- Luminaires using the Luxim LEP lamp were shown at LightFair International conferences 2010 and 2011 (http://www.luxim.com/).
- Topanga Technologies (http://topangatech.com/).
- Subject matter experts reported in February 2013 that SMUD had recently completed a field test of plasma lights.

Key research questions:

1. Can current plasma sources be utilized for a viable, energy efficient alternative to traditional "high intensity" lighting technologies?
2. Can optics incorporate needed EMI shielding (90%+ optical output)?
3. Can light-emitting diode (LED) fixture level standards be applied to plasma fixtures—for example LM79?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
General Lighting (2 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Professional design and more accurate modeling tools are now available to allow better and more efficient lighting designs
Lighting retrofits happen for many reasons which may or may not include using optics designed for the new light source. The challenge is to make it easier to improve the lighting quality and efficiency during a retrofit
Lighting should contribute to the health and productivity of occupants
General lighting should provide occupant comfort and satisfaction
The use of constantly evolving computer systems, along with changing work staff and their preferences, make a highly flexible and controllable lighting system in the workspace desirable
Users desire to have personal control over the lighting they work under and be comfortable when they can adjust it to suit varying conditions
Need for better, cheaper software to model and help people visualize a new lighting design
Existing professional design and modeling tools inadequately deal with new lighting technology and do not include all necessary characteristics
Need to develop tools that help designers and contractors optimize use of fluorescent, solid state lighting (SSL), and halogen infrared (IR) technologies by application, and design luminaire layout
Need better definition of relationship of lighting quality / safety
Need to better understand human performance, health and comfort factors related to lighting alternatives
Dynamically adjustable light sources
A recognized visual acuity metrics which accounts for eye response characteristics with regards to spectrum and light level (exterior, further than current Illuminating Engineering Society of North America (IESNA))
Ability to measure or quantify: mesopic light, dimming, glare, color.
Maximum safety for roadway lighting
Roadway lighting safety performance metric
LRC RVP; Transportation Research Board / University of Illinois at Urbana-Champaign
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

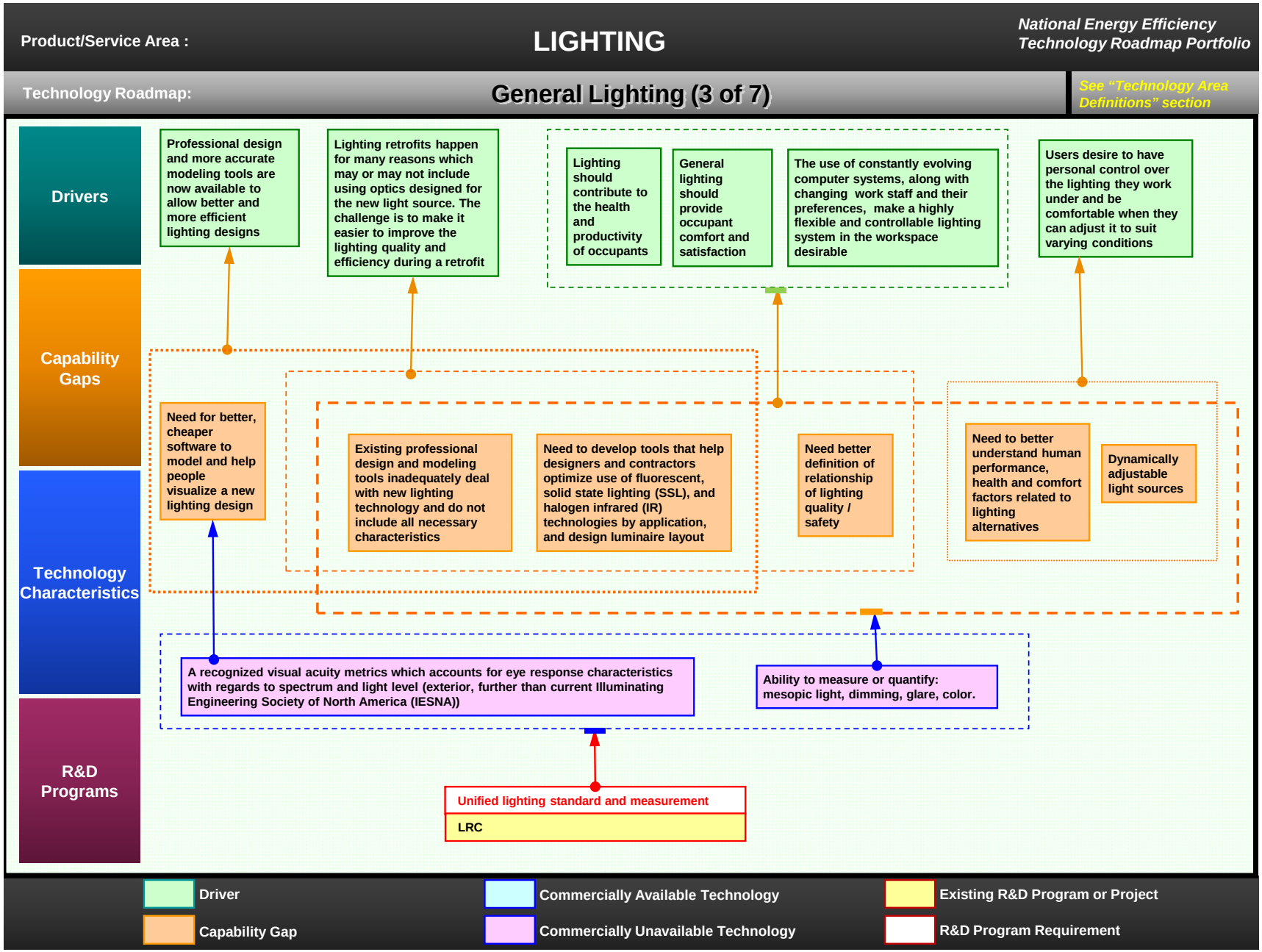
Roadway lighting safety performance metric. Consider relative visual performances SPD [?], crash statistics, and crime reports to develop roadway lighting design methodology.

Existing research: Subject matter experts in September 2012 referred to R&D at Rensselaer Polytechnic Institute Lighting Research Center (LRC) and through the Transportation Research Board of the National Academies in conjunction with the University of Illinois at Urbana-Champaign.

- LRC's research on roadway lighting includes evaluations of relative visual performance (RVP) and safety; see http://www.lrc.rpi.edu/.
- Transportation Research Board / University of Illinois research: http://trid.trb.org/view.aspx?id=1236419.

Key research questions:

1. How can roadway lighting be designed to maximize safety per watt hour (WH) for vehicles and pedestrians?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
General Lighting (3 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Professional design and more accurate modeling tools are now available to allow better and more efficient lighting designs
Lighting retrofits happen for many reasons which may or may not include using optics designed for the new light source. The challenge is to make it easier to improve the lighting quality and efficiency during a retrofit
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Need to develop tools that help designers and contractors optimize use of fluorescent, solid state lighting (SSL), and halogen infrared (IR) technologies by application, and design luminaire layout
Need better definition of relationship of lighting quality / safety
Need to better understand human performance, health and comfort factors related to lighting alternatives
Dynamically adjustable light sources
A recognized visual acuity metrics which accounts for eye response characteristics with regards to spectrum and light level (exterior, further than current Illuminating Engineering Society of North America (IESNA))
Ability to measure or quantify: mesopic light, dimming, glare, color.
Unified lighting standard and measurement
LRC
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Unified lighting standard and measurement. Explore a more intricate visual acuity standard and its measurement.

Existing research: Rensselaer Polytechnic Institute Lighting Research Center (LRC).

- LRC visual performance research: http://www.lrc.rpi.edu/programs/nlpip/lightinganswers/fullspectrum/claims.asp.
- LRC unified system of photometry: http://www.lrc.rpi.edu/resources/newsroom/pdf/2006/ImplementUnifiedSystemProject.pdf.

Key research questions:

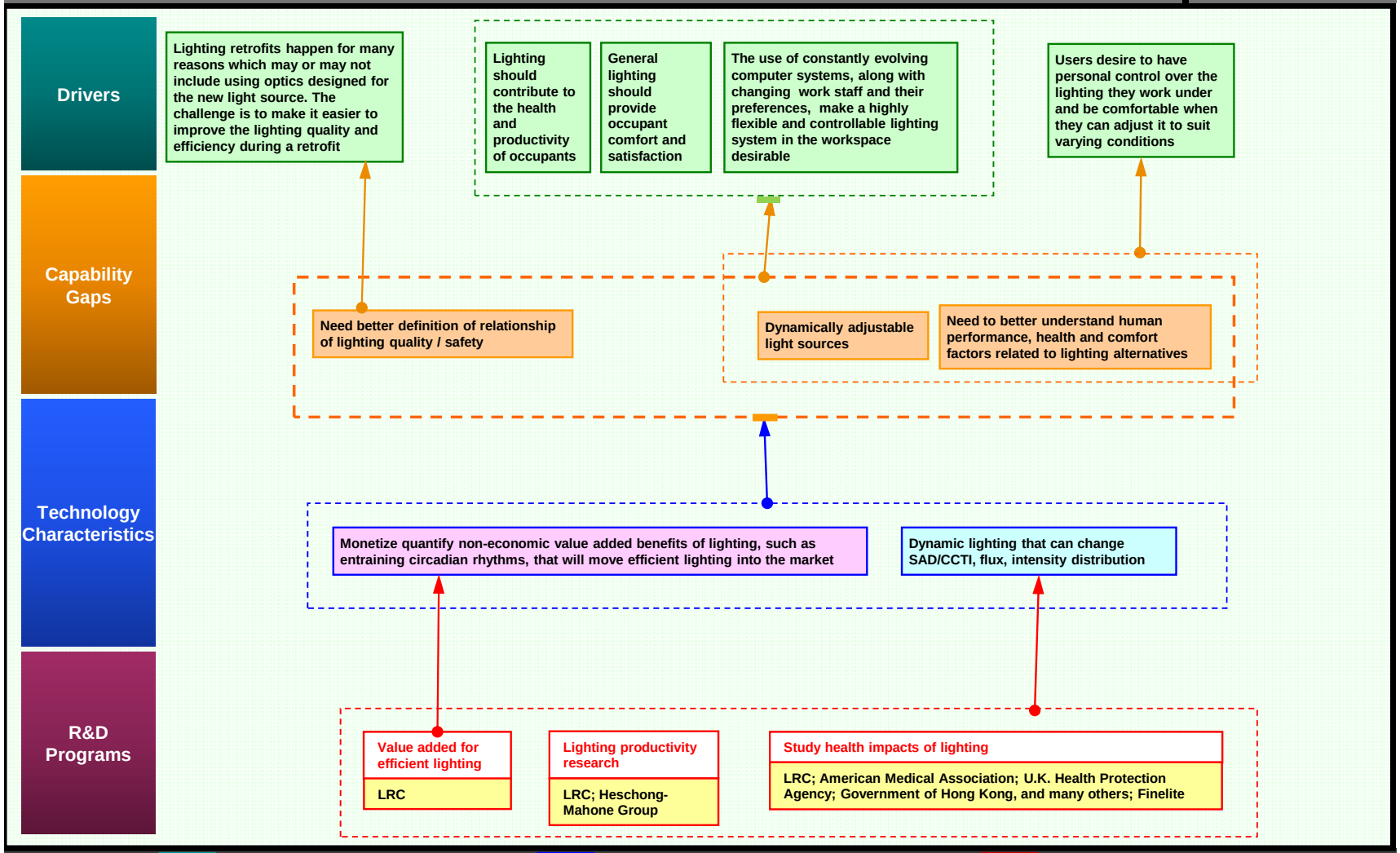
1. Can an inexpensive easy to use tool be developed that offers contractors / designers / auditors the ability to measure the correct characteristics for visual acuity (photopic, mesopic, scotopic, correlated color temperature (CCT), color rendering index (CRI))?
2. Can existing research be synthesized to create a user friendly, unified standard for lighting?
3. Can a tool be created to display visual acuity performance and expected benefit?

Product/Service Area : **LIGHTING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **General Lighting (4 of 7)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Value added for efficient lighting. Explore light health controllability and other ancillary benefits of efficient lighting.

Existing research: Rensselaer Polytechnic Institute Lighting Research Center (LRC).

- LRC Light & Health Program: http://www.lrc.rpi.edu/programs/lightHealth/index.asp.

Key research questions:

1. Quantify non-economic value-added benefits of lighting such as entraining circadian rhythms that will move efficient lighting into the market.
2. What are productivity impacts of daylighting circadian tuned lighting?

Lighting productivity research. To expand the use of some efficient lighting techniques, research is needed to better document positive impacts on productivity, building on work by the Heschong-Mahone Group (http://www.h-m-g.com/) and the Rensselaer Polytechnic Institute Lighting Research Center (LRC) (http://www.lrc.rpi.edu/).

Existing research: For Heschong-Mahone Group's completed projects in this area, see http://www.h-m-g.com/Projects/daylighting/projects-PIER.htm. For some specific current LRC projects in this area, see Appendix B; for LRC's work in this area generally, see http://www.lrc.rpi.edu/researchAreas/healthVision.asp.

Key research questions:

1. Questions not yet specified.

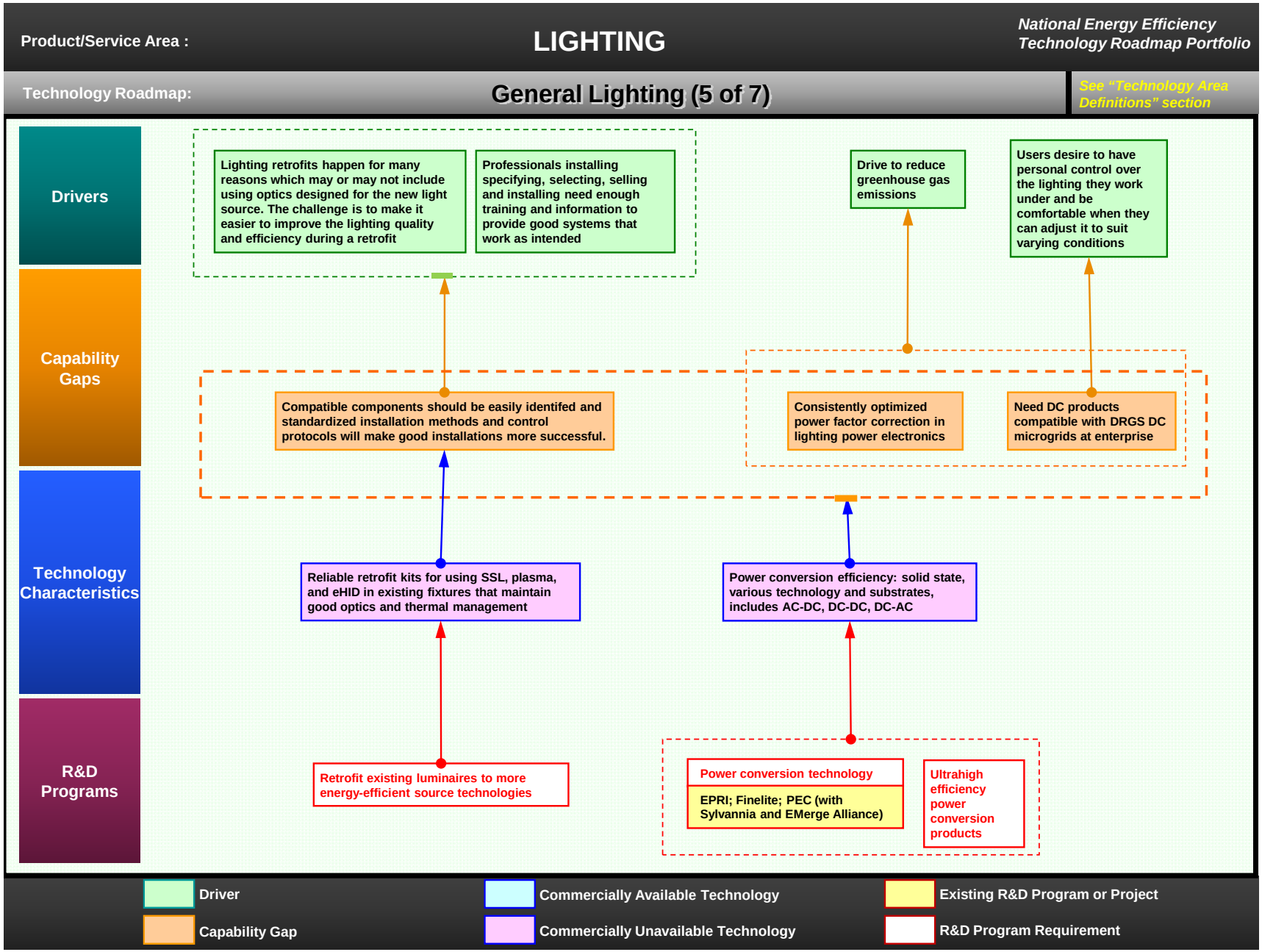
Study health impacts of lighting. To expand the utilization of some efficient lighting techniques, research is needed to better document positive impacts on human health, building on work that stakeholders indicated was ongoing at the Rensselaer Polytechnic Institute's Lighting Research Center (LRC) and other institutions. This work could potentially be informed by researchers such as Joan Roberts of Fordham University and Jennifer Veitch at the National Research Council of Canada, who are both working on designing healthy workplaces., and also Deborah Burnett and Judith Heerwagen.

Existing research: Subject matter experts stated in September 2012 that "many research studies in this area are controversial." Institutions working in this area include: Rensselaer Polytechnic Institute Lighting Research Center (LRC); American Medical Association; United Kingdom Health Protection Agency; Government of Hong Kong; Finelite.

- For LRC work in this area, see Appendix B and http://www.lrc.rpi.edu/programs/lightHealth/index.asp.
- Joan Roberts (http://www.dsm.fordham.edu/ns/roberts.html).
- Jennifer Veitch (http://www.nrc-cnrc.gc.ca/eng/projects/irc/office-lighting.html).
- Deborah Burnett, Health & Wellness Design Authority (http://www.deborahburnett.com/).
- Judith Heerwagen,Program Expert at the U.S. General Services Administration (http://www.linkedin.com/pub/judith-heerwagen/10/391/566).
- *[Summaries of other existing research pending.]*

Key research questions:

1. Questions not yet specified.


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
General Lighting (5 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Lighting retrofits happen for many reasons which may or may not include using optics designed for the new light source. The challenge is to make it easier to improve the lighting quality and efficiency during a retrofit
Professionals installing specifying, selecting, selling and installing need enough training and information to provide good systems that work as intended
Drive to reduce greenhouse gas emissions
Users desire to have personal control over the lighting they work under and be comfortable when they can adjust it to suit varying conditions
Compatible components should be easily identifed and standardized installation methods and control protocols will make good installations more successful.
Consistently optimized power factor correction in lighting power electronics
Need DC products compatible with DRGS DC microgrids at enterprise
Reliable retrofit kits for using SSL, plasma, and eHID in existing fixtures that maintain good optics and thermal management
Power conversion efficiency: solid state, various technology and substrates, includes AC-DC, DC-DC, DC-AC
Retrofit existing luminaires to more energy-efficient source technologies
Power conversion technology
EPRI; Finelite; PEC (with Sylvannia and EMerge Alliance)
Ultrahigh efficiency power conversion products
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Power conversion technology. (Summary not yet provided.)

Existing research: EPRI; Finelite; Pacific Energy Center (PEC) forthcoming withSylvannia and Emerge Alliance.

- Pacific Energy Center (PEC): http://www.pge.com/pec/.
- *[Summaries of existing research pending]*

Key research questions:

1. What substrates are best?
2. What semiconductor technology best performance voltage range?
3. How to accelerate deployment basic research into applications?

Ultrahigh efficiency power conversion products. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

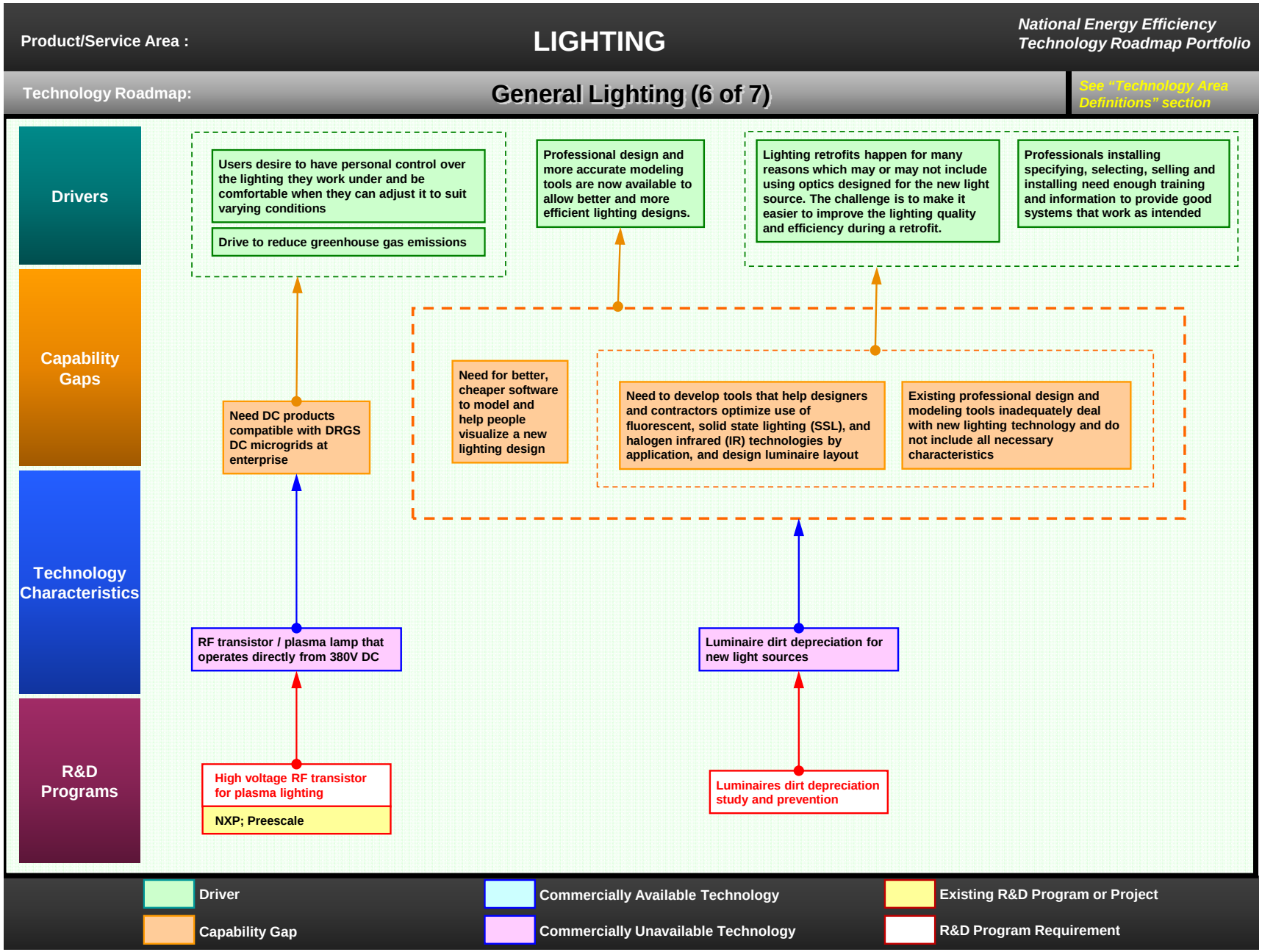
1. Which technology can achieve switching frequencies on the order of 10-20 MHZ?
2. Can function be incorporated into integrated circuits (ICs) (switching devices control, etc)?
3. Can efficiency of 97%+ be achieved?
4. Can a firm factor [form factor?] reduction of 2X or more be achieved?
5. Products should include AC-DC, DC-DC, and DC-AC conversion.

Retrofit existing luminaires to more energy-efficient source technologies. Work with Underwriters Laboratory (UL), Canadian Standards Association (CSA) International, Intertek and ETL Semko (ETL), etc., to facilitate retrofitability of existing luminaires to more energy-efficient source technologies, e.g., high-intensity discharge (HID) to solid state lighting (SSL), plasma, electronic high-intensity discharge (eHID), etc..

Existing research: None identified.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
General Lighting (6 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Users desire to have personal control over the lighting they work under and be comfortable when they can adjust it to suit varying conditions
Drive to reduce greenhouse gas emissions
Professional design and more accurate modeling tools are now available to allow better and more efficient lighting designs.
Lighting retrofits happen for many reasons which may or may not include using optics designed for the new light source. The challenge is to make it easier to improve the lighting quality and efficiency during a retrofit.
Professionals installing specifying, selecting, selling and installing need enough training and information to provide good systems that work as intended
Need DC products compatible with DRGS DC microgrids at enterprise
Need for better, cheaper software to model and help people visualize a new lighting design
Need to develop tools that help designers and contractors optimize use of fluorescent, solid state lighting (SSL), and halogen infrared (IR) technologies by application, and design luminaire layout
Existing professional design and modeling tools inadequately deal with new lighting technology and do not include all necessary characteristics
RF transistor / plasma lamp that operates directly from 380V DC
Luminaire dirt depreciation for new light sources
High voltage RF transistor for plasma lighting
NXP; Preescale
Luminaires dirt depreciation study and prevention
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

High voltage RF transistor for plasma lighting. Develop radio frequency (RF) transistor that would allow plasma lighting to work directly from 380V DC. Eliminates AC-DC conversion loss and DC-DC conversion loss (380-24V).

Existing research: NXP Semiconductors N.V. (NXP), Freescale.

- NXP Semiconductors N.V. : http://www.nxp.com/.
- Freescale: http://www.freescale.com/.
- *[Summaries of existing research pending]*

Key research questions:

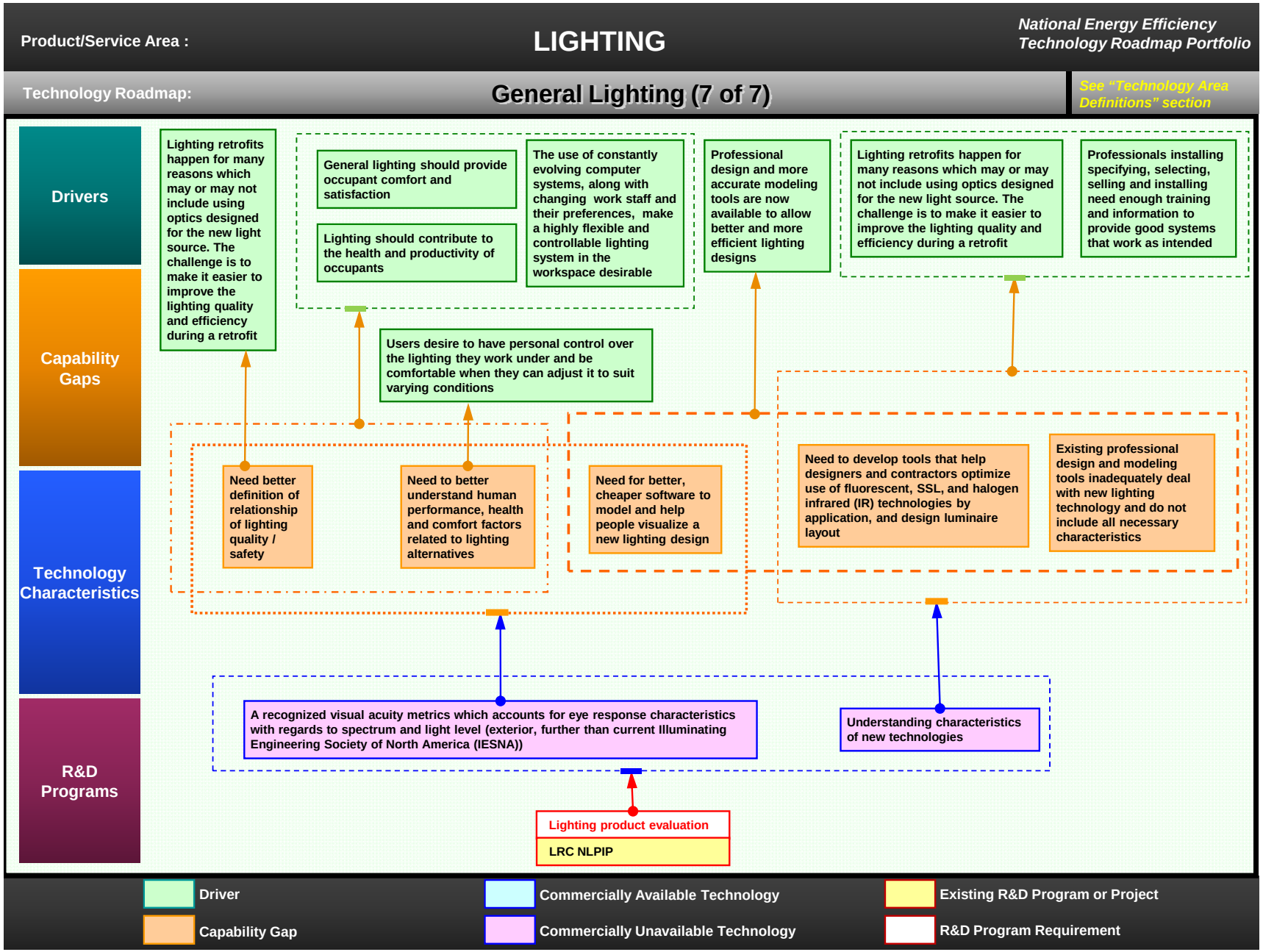
1. What devices technology would be best suited?
2. What structure would be needed to achieve high voltage?
3. Can device operate at higher frequencies (>300 MHZ)?
4. How reliable can the device be made (achieve similar reliability as current laterally diffused metal oxide semiconductor (LDMOS) technology?

Luminaires dirt depreciation study and prevention. Characterize luminaire dirt depreciation (LDD), color shift, temp, dependencies, etc., of new lighting technologies .

Existing research: None identified.

Key research questions:

1. What is the luminaire dirt depreciation (LDD) for new lighting technologies, e.g., light-emitting diode (LED), induction plasma.
2. What material/technologies can reduce luminaire dirt
3. depreciation (LDD)?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
General Lighting (7 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Lighting retrofits happen for many reasons which may or may not include using optics designed for the new light source. The challenge is to make it easier to improve the lighting quality and efficiency during a retrofit
General lighting should provide occupant comfort and satisfaction
Lighting should contribute to the health and productivity of occupants
The use of constantly evolving computer systems, along with changing work staff and their preferences, make a highly flexible and controllable lighting system in the workspace desirable
Professional design and more accurate modeling tools are now available to allow better and more efficient lighting designs
Lighting retrofits happen for many reasons which may or may not include using optics designed for the new light source. The challenge is to make it easier to improve the lighting quality and efficiency during a retrofit
Professionals installing specifying, selecting, selling and installing need enough training and information to provide good systems that work as intended
Users desire to have personal control over the lighting they work under and be comfortable when they can adjust it to suit varying conditions
Need better definition of relationship of lighting quality / safety
Need to better understand human performance, health and comfort factors related to lighting alternatives
Need for better, cheaper software to model and help people visualize a new lighting design
Need to develop tools that help designers and contractors optimize use of fluorescent, SSL, and halogen infrared (IR) technologies by application, and design luminaire layout
Existing professional design and modeling tools inadequately deal with new lighting technology and do not include all necessary characteristics
A recognized visual acuity metrics which accounts for eye response characteristics with regards to spectrum and light level (exterior, further than current Illuminating Engineering Society of North America (IESNA))
Understanding characteristics of new technologies
Lighting product evaluation
LRC NLPIP
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

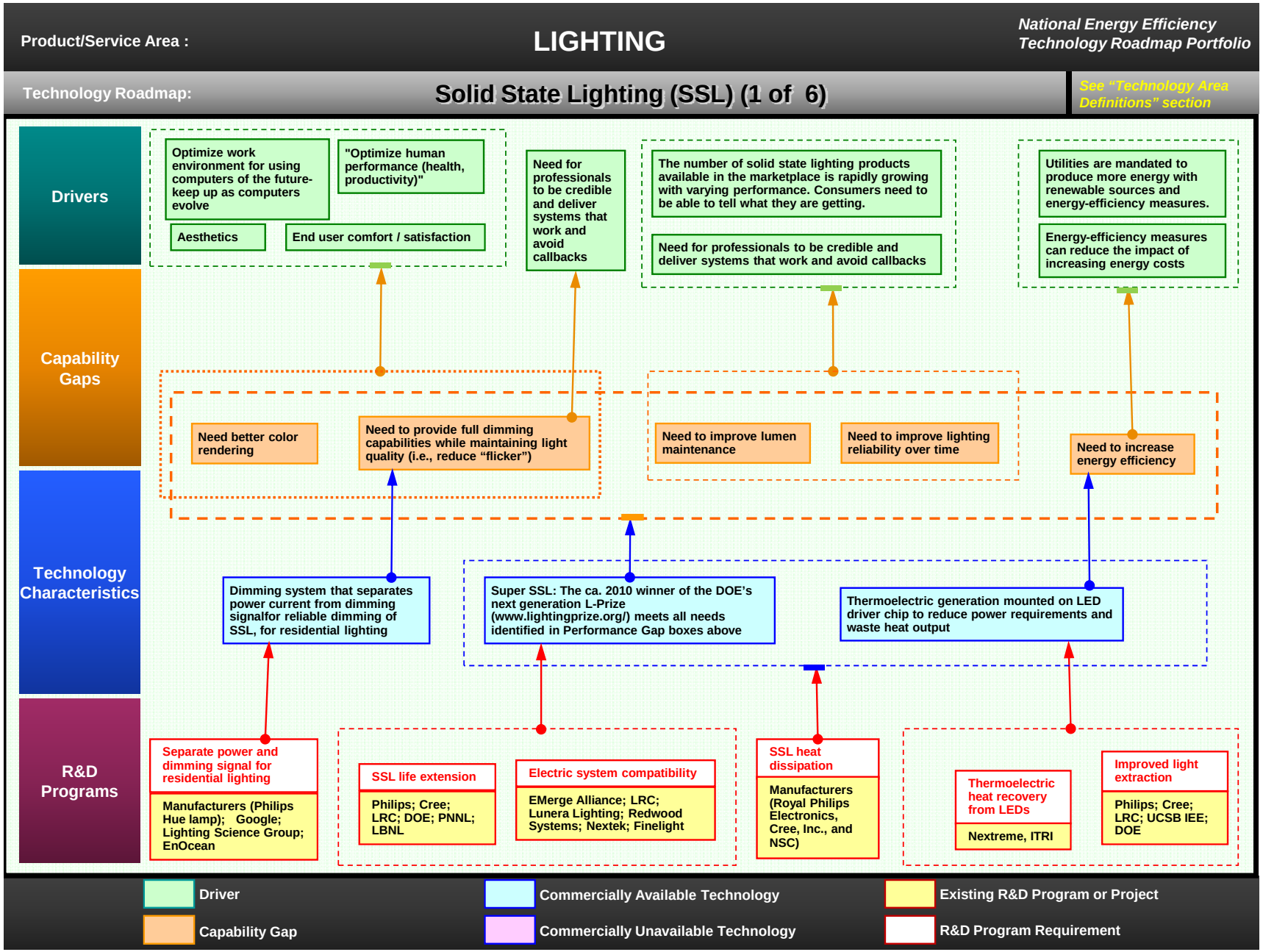
Lighting product evaluation. Evaluate characteristics of new lighting technologies and disseminate result to lighting specifiers.

Existing research: Rensselaer Polytechnic Institute Lighting Research Center (LRC) National Lighting Product Information Program(NLPIP).

- LRC NLPIP: http://www.lrc.rpi.edu/programs/NLPIP/index.asp.
- *[Summaries of existing research pending]*

Key research questions:

1. What are the reluctant characteristics of plasma lighting and how do individual products perform?
2. What are photometric and dimming characterizations of light-emitting diode (LED) MRIGS? *[Note: Unsure if "MRIGS" is the correct transcription of data provided by subject matter experts and, if so, what "MRIGS" means.]*


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Solid State Lighting (SSL) (1 of 6)
See "Technology Area Definitions" section
Drivers
Optimize work environment for using computers of the future-keep up as computers evolve
"Optimize human performance (health, productivity)"
Aesthetics
End user comfort / satisfaction
Need for professionals to be credible and deliver systems that work and avoid callbacks
The number of solid state lighting products available in the marketplace is rapidly growing with varying performance. Consumers need to be able to tell what they are getting.
Need for professionals to be credible and deliver systems that work and avoid callbacks
Utilities are mandated to produce more energy with renewable sources and energy-efficiency measures.
Energy-efficiency measures can reduce the impact of increasing energy costs
Capability Gaps
Need better color rendering
Need to provide full dimming capabilities while maintaining light quality (i.e., reduce "flicker")
Need to improve lumen maintenance
Need to improve lighting reliability over time
Need to increase energy efficiency
Technology Characteristics
Dimming system that separates power current from dimming signalfor reliable dimming of SSL, for residential lighting
Super SSL: The ca. 2010 winner of the DOE's next generation L-Prize (www.lightingprize.org/) meets all needs identified in Performance Gap boxes above
Thermoelectric generation mounted on LED driver chip to reduce power requirements and waste heat output
R&D Programs
Separate power and dimming signal for residential lighting
Manufacturers (Philips Hue lamp); Google; Lighting Science Group; EnOcean
SSL life extension
Philips; Cree; LRC; DOE; PNNL; LBNL
Electric system compatibility
EMerge Alliance; LRC; Lunera Lighting; Redwood Systems; Nextek; Finelight
SSL heat dissipation
Manufacturers (Royal Philips Electronics, Cree, Inc., and NSC)
Thermoelectric heat recovery from LEDs
Nextreme, ITRI
Improved light extraction
Philips; Cree; LRC; UCSB IEE; DOE
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

SSL heat dissipation. Excess heat directly affects both short-term and long term light-emitting diode (LED) performance. The short-term (reversible) effects are color shift and reduced light output, while the long-term effect is accelerated lumen depreciation and thus shortened useful life.

Existing research: Research is ongoing at Royal Philips Electronics, Cree, Inc., and National Semiconductor Corporation (NSC); ongoing research from private firms tends largely to be proprietary and, therefore, not thoroughly or consistently reported through companies' web pages.

- Cree, Inc.: http://cree.com/.
- Philips Research conducts lighting R&D for Royal Philips Electronics; see http://www.research.philips.com/index.html.
- NSC offers a variety of LED thermal management solutions for exterior and interior applications in commercial and residential buildings (http://www.national.com/en/led/tempsensors.html).

Key research questions:

1. Are there innovative materials that can be used for heat dissipation?
2. Innovative active or passive cooling systems that have market potential?
3. New structure design approaches to address heat dissipation (such as chaotic air flow)?

SSL life extension. Electrical and thermal design of the light-emitting diode (LED) system or fixture determine how long LEDs will last and how much light they will provide. Driving the LED at higher than rated current will increase relative light output but decrease useful life. Operating the LED at higher than design temperature will also decrease useful life significantly.

Existing research: Research is ongoing at the Lighting Research Center (LRC), Pacific Northwest National Laboratory (PNNL), and the Lawrence Berkeley National Laboratory (LBNL) as well as Royal Philips Electronics, Cree, Inc., and other manufacturers; ongoing research from private firms tends largely to be proprietary and, therefore, not thoroughly or consistently reported through companies' web pages.

Subject matter experts also indicated in September 2012 that the Department of Energy's Solid State Lighting program is already evaluating this area around the "droop" effect.

- LBNL's ongoing research in this area is identified in Appendix B.
- Philips Research conducts lighting R&D for Royal Philips Electronics; see http://www.research.philips.com/index.html.
- Cree, Inc.: http://cree.com/.
- *[Summaries of other existing research pending]*

Key research questions:

1. What is the incremental cost impact to maintain rated current and temperature levels?

Continued . . .

Improved light extraction. Constant development of higher efficacy light emitting diode (LED) / driver packages is ongoing with the goal of more lumens per watt without sacrificing lamp life.

Existing research: Research is ongoing at the Lighting Research Center (LRC) and the Lawrence Berkeley National Laboratory (LBNL) as well as Royal Philips Electronics, Cree, Inc., and other manufacturers; ongoing research from private firms tends largely to be proprietary and, therefore, not thoroughly or consistently reported through companies' web pages.

Subject matter experts also indicated in September 2012 that there was ongoing research at the University of California Santa Barbara's Institute for Energy Efficiency (IEE) and that the Department of Energy's Solid State Lighting program is evaluating and promoting this analysis.

- LRC's ongoing research in this area is identified in Appendix B.
- LBNL's ongoing research in this area is identified in Appendix B.
- Philips Research conducts lighting R&D for Royal Philips Electronics; see http://www.research.philips.com/index.html.
- Cree, Inc.: http://cree.com/.
- *[Summaries of other existing research pending]*

Key research questions:

1. What is the life cycle development curve look like for SSL chips?
2. When do we expect to hit the theoretical limit for SSL efficacy?

Thermoelectric heat recovery from LEDs. Heat dissipation is essential to good performance of light-emitting diode (LED) lighting. One approach suggested for dissipating the heat is to actually generate electricity from the generated heat using thermoelectric (or thermo-electronic) devices (similar to photovoltaic (PV), but they operate on heat, not light), increasing the effective efficiency of the system.

Existing research: Nextreme Thermal Solutions and the Industrial Technology Research Institute (ITRI) in Taiwan are among the institutions researching this area.

- Nextreme Thermal Solutions has developed a number of technologies to generate power from waste heat. These technologies include their Thermobility™ system that converts heat into electricity for low-power wireless applications (http://www.nextreme.com/pages/power_gen/apps/thermobility.shtml), and thin film thermoelectric materials (http://www.nextreme.com/pages/power_gen/power_gen.shtml).
- ITRI reported in 2005 on a project involving the cooling performance of a silicon-based thermoelectric device on high power LEDs; see Appendix B for more information.

Key research questions:

1. Is it cost effective?
2. What is the value to SSL specifically?
3. Is a solution commercially available?
4. What is the efficiency savings for this solution?

Separate power and dimming signal for residential lighting. Most residential light circuits use 2 wires for power. Develop an inexpensive retrofit solution for SSL with dimming, for example wireless batteryless control.

Existing research: Manufacturers (Philips Hue lamp), Google, Lighting Science Group, enOcean.

- *[Summaries of existing research pending]*

Key research questions:

1. Develop possible cost-effective wireless, batteryless dimmers.
2. Can a robust dimmer used with various numbers of lamps without flicker, popcorning, drop-out, etc., be developed?
3. Develop fixtures and lamps compatible with wireless dimming controls can a low-cost wireless/batteryless dimmer be developed at a cost acceptable to consumers.
4. What are customer expectations for wireless dimmers and willingness to pay?

Continued . . .

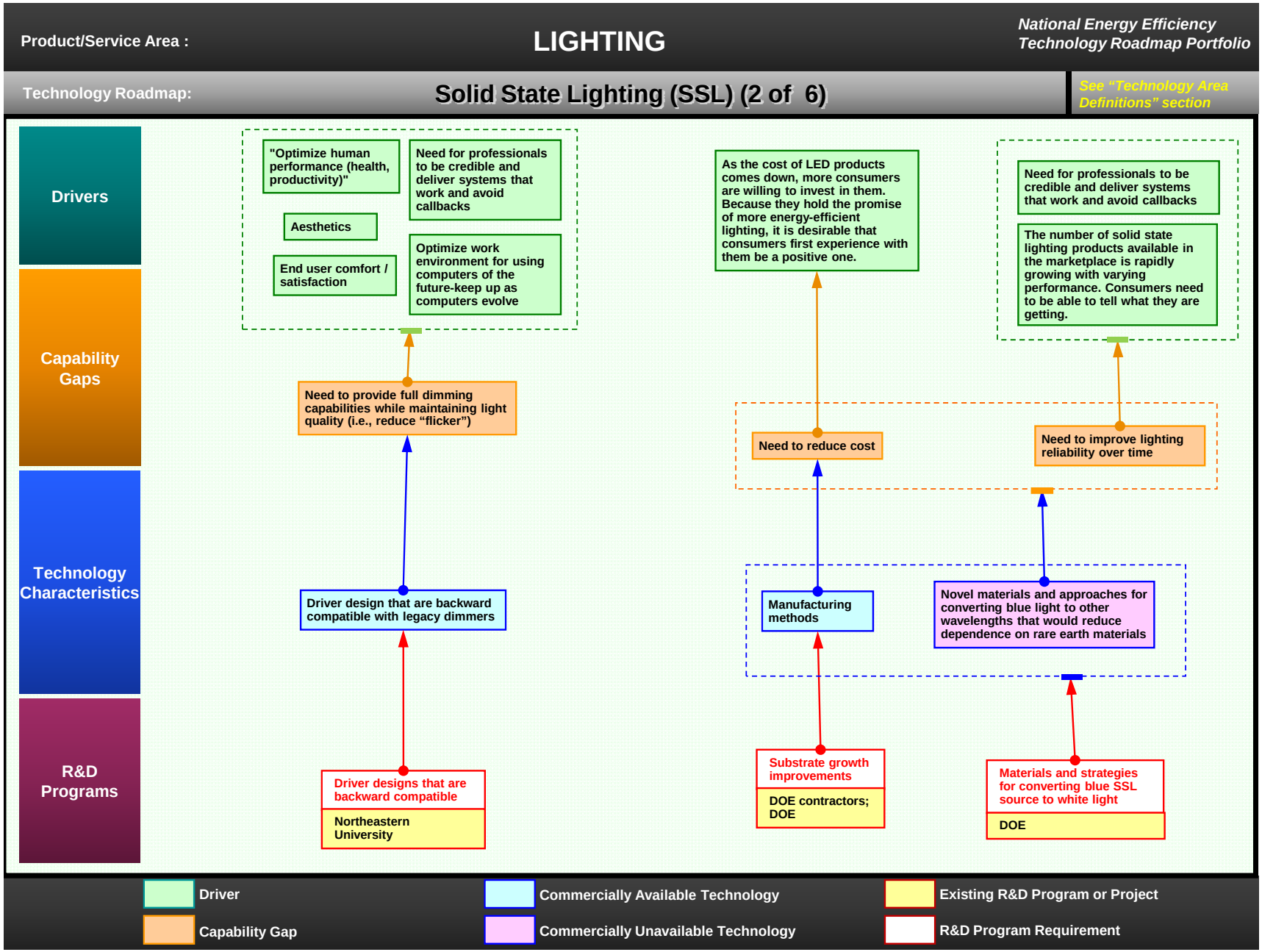
Electric system compatibility. Unlike most other light sources, most light emitting diode (LED) products require conversion of alternating current (AC) to direct current (DC) power, which introduces system inefficiencies.

Existing research: Multiple parties are researching this issue, including Emerge Alliance and the Rensselaer Polytechnic Institute Lighting Research Center (LRC) and the private firms Lunera Lighting, Inc., Redwood Systems, Inc., and Nextek, Inc.. Ongoing research from private firms tends largely to be proprietary and, therefore, not thoroughly or consistently reported through companies' web pages.

- Emerge Alliance is developing standards for DC power for commercial buildings, which would provide an environment where LEDs could be used directly. See Appendix B.
- LRC is researching electronic walls and ceilings that are compatible with LEDs. See Appendix B for more information.

Key research questions:

1. What is the viability of AC-powered SSL products?
2. What is the viability of more efficient AC-DC conversion?
3. Acceptable flicker level needed?
4. A flicker standard is needed to ensure the safety and productivity of normal and at-risk populations.


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Solid State Lighting (SSL) (2 of 6)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
"Optimize human performance (health, productivity)"
Need for professionals to be credible and deliver systems that work and avoid callbacks
Aesthetics
End user comfort / satisfaction
Optimize work environment for using computers of the future-keep up as computers evolve
As the cost of LED products comes down, more consumers are willing to invest in them. Because they hold the promise of more energy-efficient lighting, it is desirable that consumers first experience with them be a positive one.
Need for professionals to be credible and deliver systems that work and avoid callbacks
The number of solid state lighting products available in the marketplace is rapidly growing with varying performance. Consumers need to be able to tell what they are getting.
Need to provide full dimming capabilities while maintaining light quality (i.e., reduce "flicker")
Need to reduce cost
Need to improve lighting reliability over time
Driver design that are backward compatible with legacy dimmers
Manufacturing methods
Novel materials and approaches for converting blue light to other wavelengths that would reduce dependence on rare earth materials
Driver designs that are backward compatible
Northeastern University
Substrate growth improvements
DOE contractors; DOE
Materials and strategies for converting blue SSL source to white light
DOE
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Materials and strategies for converting blue SSL source to white light. Rare earth phosphors are to be found in China but are expensive and scarce. Can we shift to a new source of phosphors or develop a new method to produce white light from blue LED?

Existing research: .S. Department of Energy (DOE) .

- *[Summaries of existing research pending]*

Key research questions:

1. What materials could replace rare earth phosphors to convert blue to white light?
2. What new processes could replace phosphoresce to convert blue to white (such as quantum dots)?
3. What is viability of using phosphors reclaimed from expired fluorescent tubes for production of SSL?
4. What is the life cycle benefit/cost of new light color conversion strategies?

Substrate growth improvements. Light-emitting diodes (LEDs) are grown on substrates and there is ongoing research to improve the process for such things as: higher external quantum efficiency performance, better electrostatic discharge durability, simple low-cost fabrication, high product yield with high brightness, and better heat management..

Existing research: The U.S. Department of Energy (DOE) sponsors research in this area at various contractors and has also developed a Solid State Lighting roadmap.

- DOE's ongoing research and development in this area can be found in Appendix B.
- DOE's SSL technology roadmaps can be accessed at http://www1.eere.energy.gov/buildings/ssl/techroadmaps.html.

Key research questions:

1. What innovations exist for process improvement in substrate growth?

Driver designs that are backward compatible. There are known challenges with SSL compatibility with legacy dimmers. Research is needed to explore options for backward compatibility as most consumers will not want to replace their dimmers.

Existing research: Northeastern University.

- *[Summaries of existing research pending]*

Key research questions:

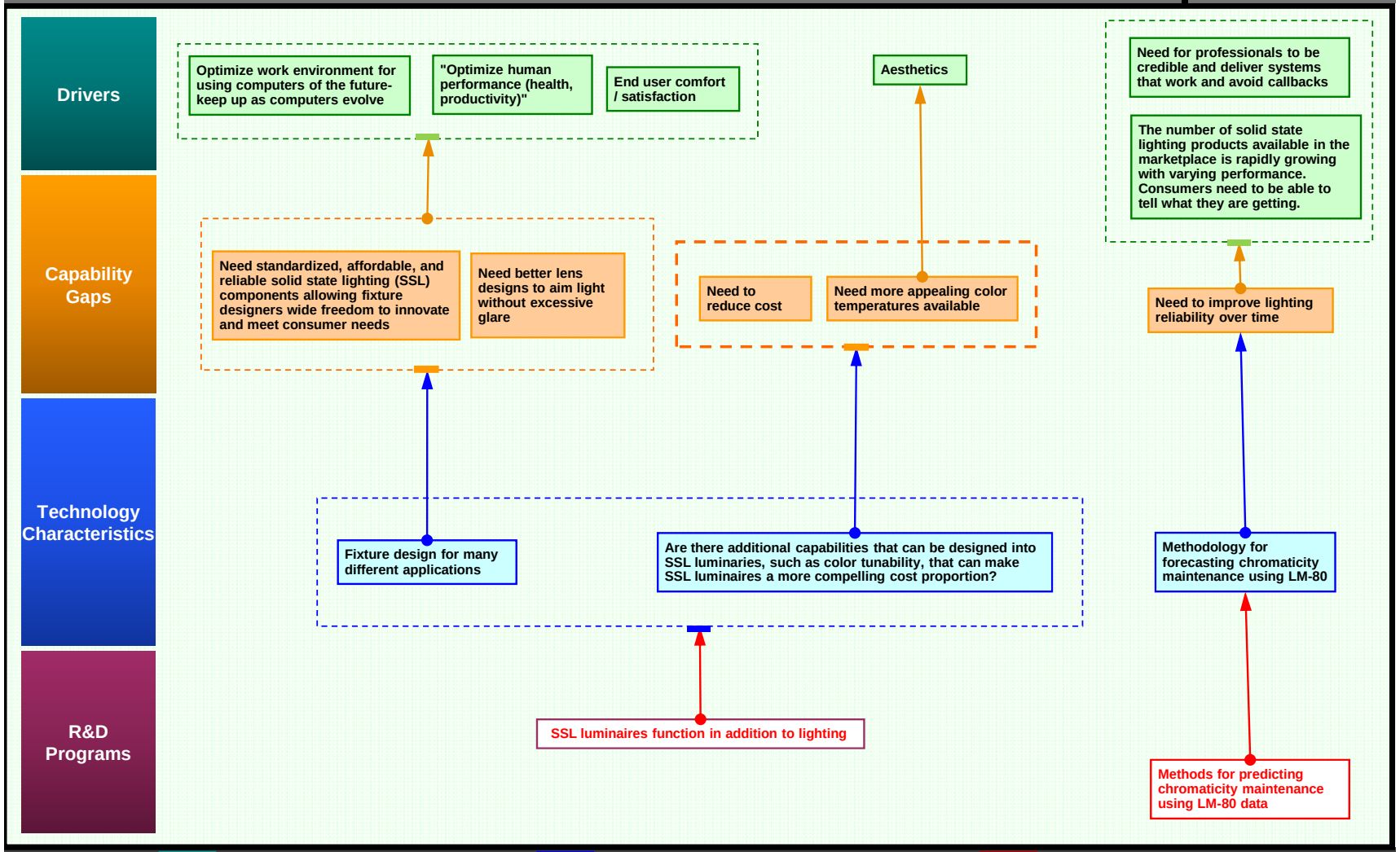
1. What solutions exist to create backwards compatibility?
2. What is the impact on the cost of the SLL product?
3. What capabilities are needed to make a solution realistic?

Product/Service Area : **LIGHTING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Solid State Lighting (SSL) (3 of 6)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

SSL luminaires function in addition to lighting. Light-emitting diodes (LEDs) are microelectrons: They have communication or other capabilities. Can we capitalize on these capabilities to boost market acceptance of the new technology? Examples include an integrated chilled beam 'luminaire' from Troxx that provides direct and indirect lighting plus heating, cooling, sprinkler, smoke detector, occupancy sensor, public address speaker, internet and AC sockets, etc. For another example, color-changing LED luminaires can be controlled to support the physiology of diurnal rhythms, with the potential to improve health and productivity with non-energy benefits that could be much more valuable than energy savings

Existing research: .None identified.

Key research questions:

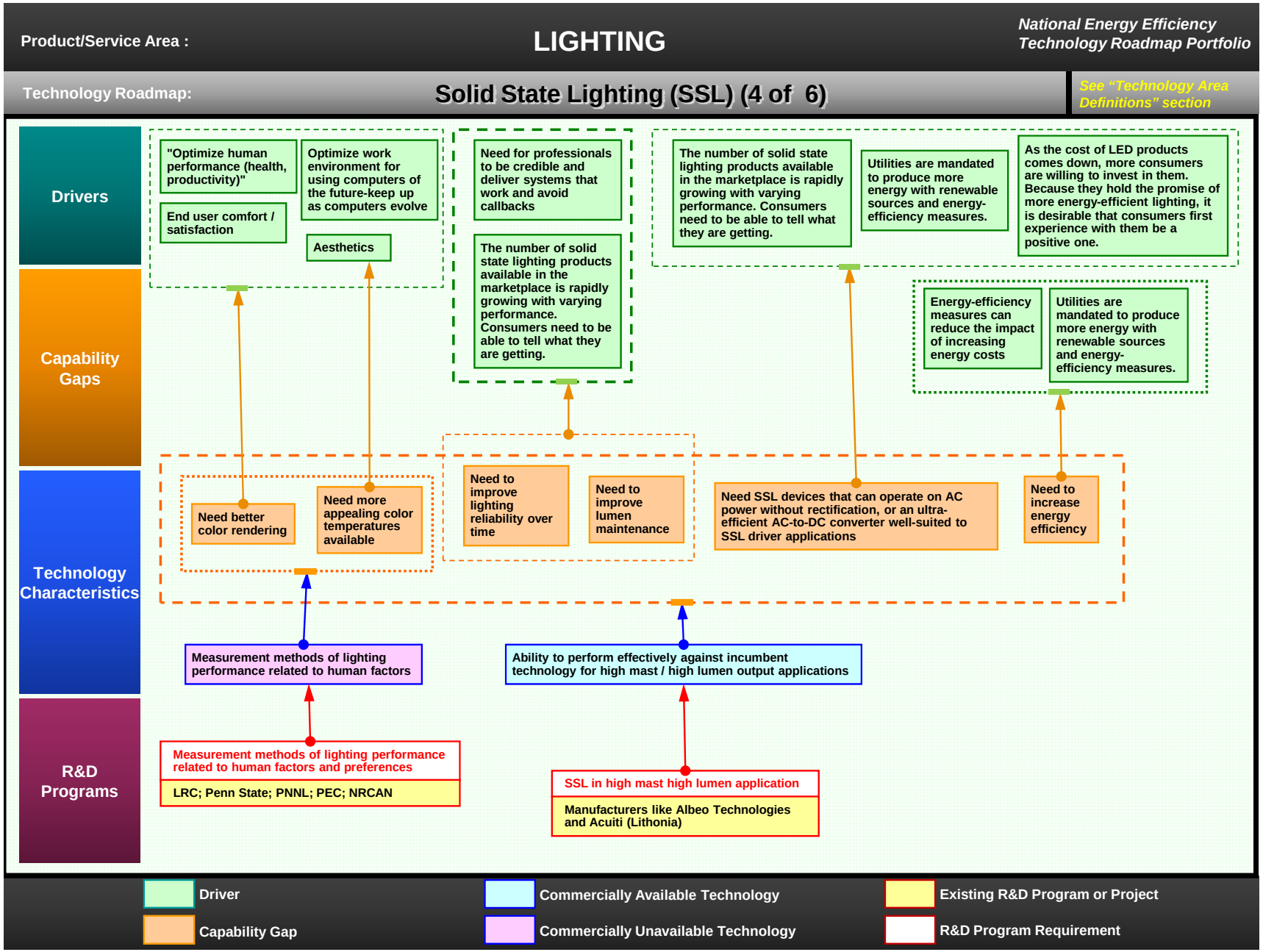
1. What functions can SSL luminaires perform in addition to illumination?
2. Can added functions be developed and marketed cost effectively?
3. Will consumers pay for added functions in SSL luminaires?

Methods for predicting chromaticity maintenance using LM-80 data. There are no consensus methods for predicting long-term chromaticity maintenance. Better understanding of the factors that cause changes in chromaticity over time might allow development of models that could be used to predict chromaticity maintenance.

Existing research: None identified.

Key research questions:

1. What are the degradation factors in phosphors and what are their dependent variables?
2. What are the degradation factors in LEDs that cause changes in the wavelength of emissions, and what are their depend variables?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Solid State Lighting (SSL) (4 of 6)
See "Technology Area Definitions" section
Drivers
"Optimize human performance (health, productivity)"
Optimize work environment for using computers of the future-keep up as computers evolve
End user comfort / satisfaction
Aesthetics
Need for professionals to be credible and deliver systems that work and avoid callbacks
The number of solid state lighting products available in the marketplace is rapidly growing with varying performance. Consumers need to be able to tell what they are getting.
The number of solid state lighting products available in the marketplace is rapidly growing with varying performance. Consumers need to be able to tell what they are getting.
Utilities are mandated to produce more energy with renewable sources and energy-efficiency measures.
As the cost of LED products comes down, more consumers are willing to invest in them. Because they hold the promise of more energy-efficient lighting, it is desirable that consumers first experience with them be a positive one.
Capability Gaps
Energy-efficiency measures can reduce the impact of increasing energy costs
Utilities are mandated to produce more energy with renewable sources and energy-efficiency measures.
Technology Characteristics
Need better color rendering
Need more appealing color temperatures available
Need to improve lighting reliability over time
Need to improve lumen maintenance
Need SSL devices that can operate on AC power without rectification, or an ultra-efficient AC-to-DC converter well-suited to SSL driver applications
Need to increase energy efficiency
Measurement methods of lighting performance related to human factors
Ability to perform effectively against incumbent technology for high mast / high lumen output applications
R&D Programs
Measurement methods of lighting performance related to human factors and preferences
LRC; Penn State; PNNL; PEC; NRCAN
SSL in high mast high lumen application
Manufacturers like Albeo Technologies and Acuiti (Lithonia)
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Measurement methods of lighting performance related to human factors and preferences. For example, simulate the variation of lighting levels of daylight. For example, flicker spectrum. For example, blue/red content versus rhythms.

Existing research: Rensselaer Polytechnic Institute Lighting Research Center (LRC), Pennsylvania State University, Pacific Northwest National Laboratory (PNNL), Pacific Energy Center (PEC), Natural Resources Canada (NRCAN), University of California Davis California Lighting Technology Center (CLTC).

- For CLTC work in this area, see Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. What effects of lighting on human physiology need new standardized measurements to characterize lighting performance?
2. What metric should be defined to characterize light effect on human factors?
3. What is the effect of cut color changing luminaires on human factors?

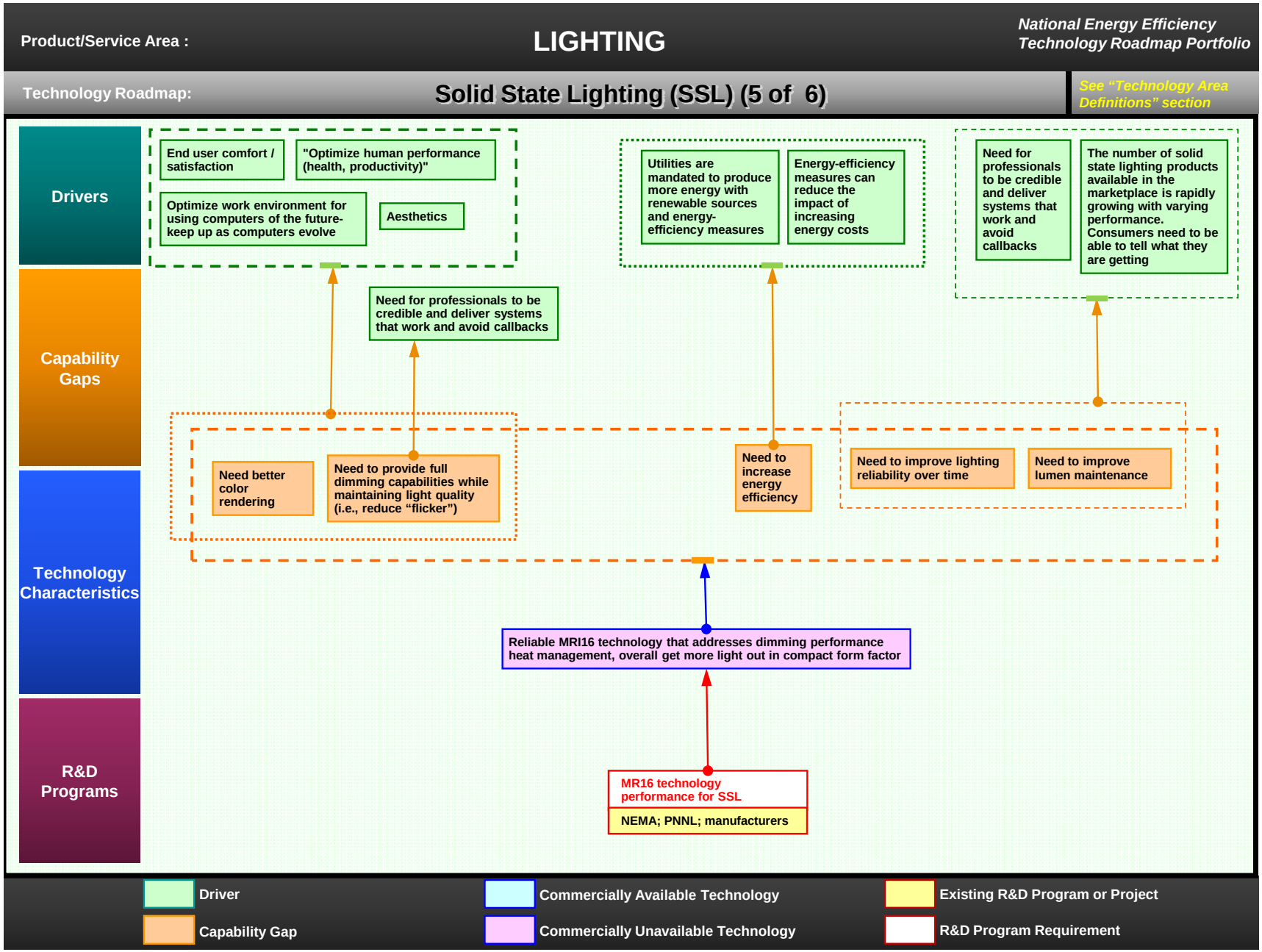
SSL in high mast high lumen application. SSL has not penetrated the high mast high lumen market. More research is needed to determine minimum performance requirements for the wide variety of applications.

Existing research: Equivalent functionality includes Nancy Clanton and Associates' interstate lighting on a viaduct in Trinidad, CO, and applications along the C-470 highway in Denver, etc. Subject matter experts identified ongoing R&D at manufacturers like Albeo Technologies and Acuiti (Lithonia).

- *[Summaries of existing research pending]*

Key research questions:

1. What testing protocols are required to prove performance of high mast high lumen SSL applications?
2. What testing protocols are necessary to prove SSL can meet or exceed strict dept of transportation performance requirements?
3. Can a standard be developed to insure minimum performance is met even though a partial failure occurs?
4. What testing protocols could prove the functional performance of new SSL form factors that replace existing high mast high lumen applications?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Solid State Lighting (SSL) (5 of 6)
See "Technology Area Definitions" section
Drivers
End user comfort / satisfaction
"Optimize human performance (health, productivity)"
Optimize work environment for using computers of the future-keep up as computers evolve
Aesthetics
Utilities are mandated to produce more energy with renewable sources and energy-efficiency measures
Energy-efficiency measures can reduce the impact of increasing energy costs
Need for professionals to be credible and deliver systems that work and avoid callbacks
The number of solid state lighting products available in the marketplace is rapidly growing with varying performance. Consumers need to be able to tell what they are getting
Capability Gaps
Need for professionals to be credible and deliver systems that work and avoid callbacks
Need better color rendering
Need to provide full dimming capabilities while maintaining light quality (i.e., reduce "flicker")
Need to increase energy efficiency
Need to improve lighting reliability over time
Need to improve lumen maintenance
Technology Characteristics
Reliable MRI16 technology that addresses dimming performance heat management, overall get more light out in compact form factor
R&D Programs
MR16 technology performance for SSL
NEMA; PNNL; manufacturers
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

MR16 technology performance for SSL. The MR16 form factor has additional challenges due to its size and installation on low voltage circuits (presence of transformers). Purpose of R&D work is to look at solutions to resolve issues of dimmability, heat management, and overall form limitation.

Existing research: National Electrical Manufacturers Association (NEMA), Pacific Northwest National Laboratory (PNNL), manufacturers.

- *[Summaries of existing research pending]*

Key research questions:

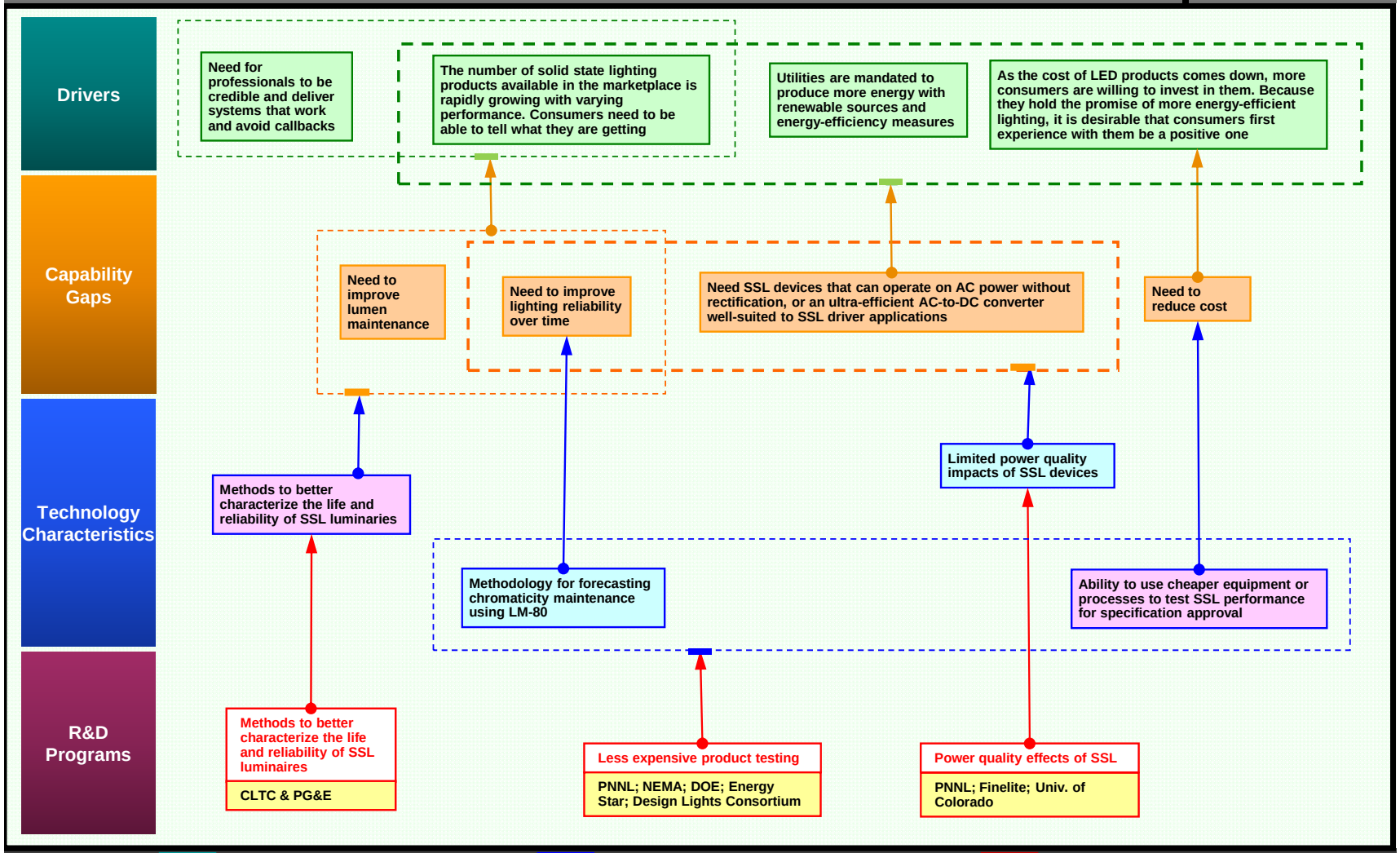
1. What solutions are available to increase compatibility of MR16, transformer, and dimmer?
2. Solutions for better heat management and therefore longevity of MR16?
3. Innovations for maximizing higher lumen output in a small package like MR16s?

Product/Service Area : **LIGHTING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Solid State Lighting (SSL) (6 of 6)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Methods to better characterize the life and reliability of SSL luminaires. There are no consensus methods for characterizing the life and reliability of SSL luminaires. Many manufactures presently use L70 lamp maintenance as surrogate for life. This is an improper characterization. Better methods are needed.

Existing research: University of California Davis California Lighting Technology Center (CLTC) / Pacific Gas & Electric.

- *[Summaries of existing research pending]*

Key research questions:

1. Is it possible to develop a unified metric that captures lumen maintenance and all other major failure modes?
2. Would it be best to develop a reliability metric not expressed in hours or years?

Power quality effects of SSL. We do not know what effects are on building power quality, from SSL lighting strategies. We need to study effects and mitigation strategies.

Existing research: Pacific Northwest National Laboratory (PNNL); Finelite, University of Colorado.

- *[Summaries of existing research pending]*

Key research questions:

1. How does SSL operation affect building-level power quality (partial building: system effects)?
2. What would be the impact on building power quality of full building SSL lighting strategy?
3. What are possible mitigation strategies of power quality problems from SSL?

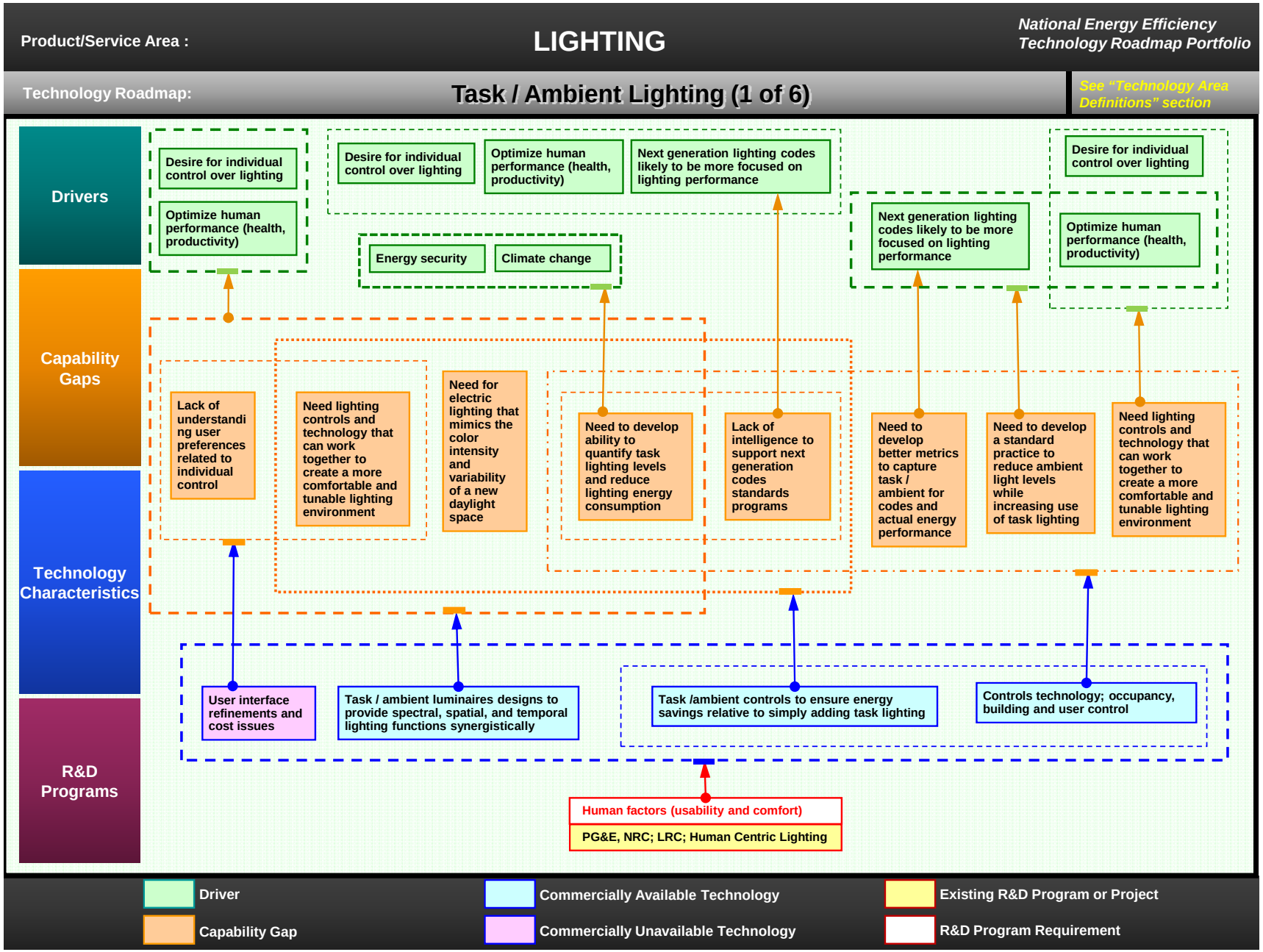
Less expensive product testing. Cheaper equipment and methods for product performance testing is needed as approach for reducing overall product costs. Are there alternatives to LM-80, LM-79, etc. for validating performance?

Existing research: Pacific Northwest National Laboratory (PNNL), National Electrical Manufacturers Association (NEMA), U.S. Department of Energy (DOE), Energy Star, Design Lights Consortium.

- *[Summaries of existing research pending]*

Key research questions:

1. What equipment and methods are less expensive and accurate enough?
2. What is accurate enough?
3. What portion of total product cost is for testing?
4. What impact does the current testing needs have on time to market?
5. What accurate methods can be developed to project luminaire performance on similar luminaires in the product family?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Task / Ambient Lighting (1 of 6)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Desire for individual control over lighting
Optimize human performance (health, productivity)
Desire for individual control over lighting
Optimize human performance (health, productivity)
Next generation lighting codes likely to be more focused on lighting performance
Energy security
Climate change
Next generation lighting codes likely to be more focused on lighting performance
Desire for individual control over lighting
Optimize human performance (health, productivity)
Lack of understanding user preferences related to individual control
Need lighting controls and technology that can work together to create a more comfortable and tunable lighting environment
Need for electric lighting that mimics the color intensity and variability of a new daylight space
Need to develop ability to quantify task lighting levels and reduce lighting energy consumption
Lack of intelligence to support next generation codes standards programs
Need to develop better metrics to capture task / ambient for codes and actual energy performance
Need to develop a standard practice to reduce ambient light levels while increasing use of task lighting
Need lighting controls and technology that can work together to create a more comfortable and tunable lighting environment
User interface refinements and cost issues
Task / ambient luminaires designs to provide spectral, spatial, and temporal lighting functions synergistically
Task /ambient controls to ensure energy savings relative to simply adding task lighting
Controls technology; occupancy, building and user control
Human factors (usability and comfort)
PG&E, NRC; LRC; Human Centric Lighting
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Human factors (usability and comfort). The elements for broad application are present, but need human factors R&D on design and control approaches to realize the potential.

Existing research: Some work has been done in this area, but there is still much to be explored. Pacific Gas & Electric (PG&E) has done some work in this area. This research could potentially be informed by Professors Joan Roberts of Fordham University and Jennifer Veitch at the National Research Council (NRC) of Canada, who are both working on designing healthy workplaces. There is also ongoing work at the Rensselaer Polytechnic Institute Lighting Research Center (LRC) and Human Centric Lighting.

- PG&E in 2009 completed a study of how occupants respond to task-ambient lighting systems (http://www.etcc-ca.com/component/content/article/21/2892-high-efficiency-office-low-ambienttask-lighting-large-office-).
- Professor Veitch, Senior Research Officer of the NRC's Indoor Environment Research Program (http://www.nrc-cnrc.gc.ca/eng/projects/irc/office-lighting.html) reported in late February 2012 that there are some relevant findings from the NRC's work in this area, and details at http://www.nrc-cnrc.gc.ca/eng/programs/irc/ie.html.
- Joan Roberts (http://www.dsm.fordham.edu/ns/roberts.html).
- Human Centric Lighting: http://humancentriclighting.com/.
- *[Summaries of other existing research pending]*

Key research questions:

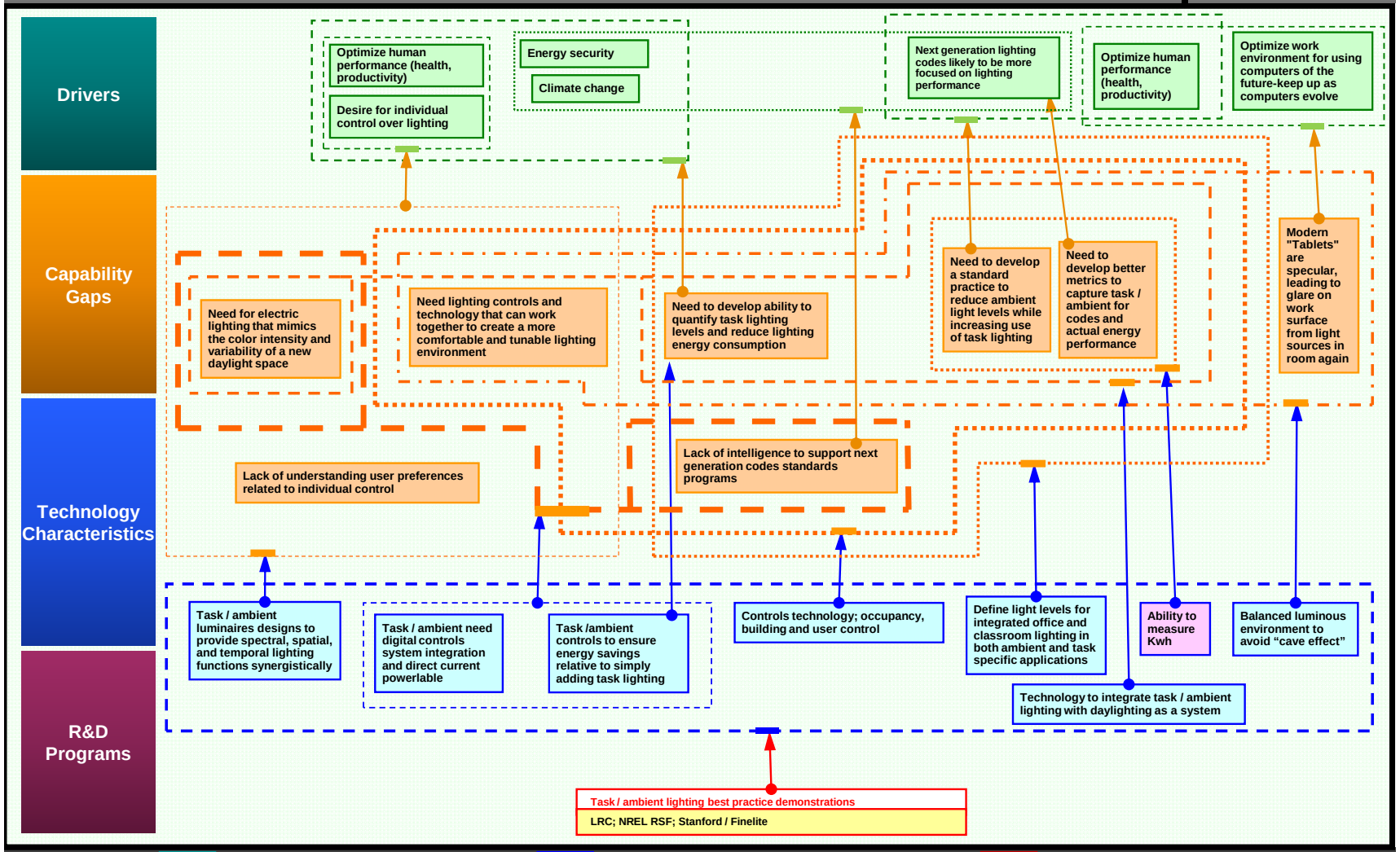
1. Questions not yet identified.

Product/Service Area : **LIGHTING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Task / Ambient Lighting (2 of 6)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

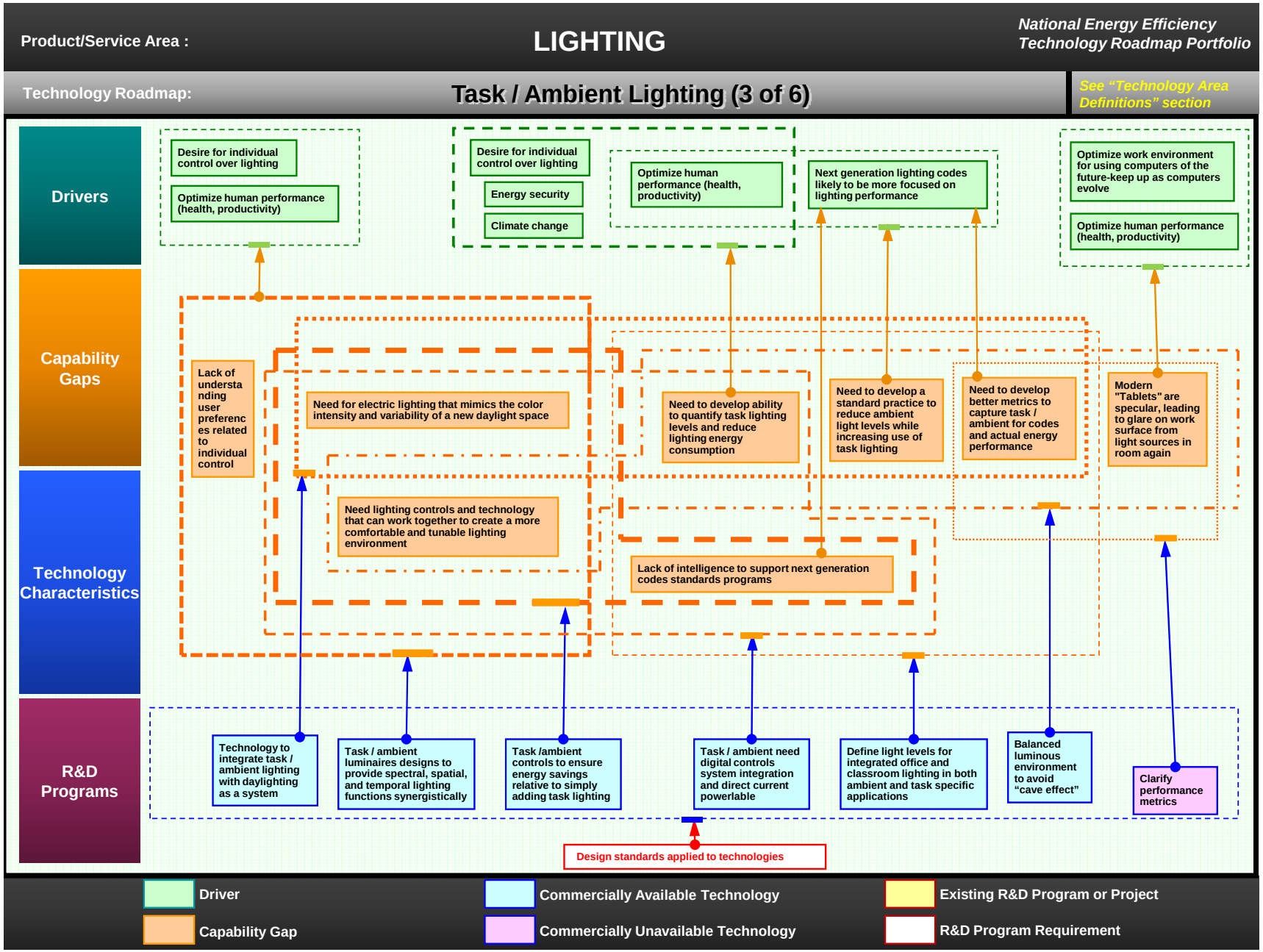
Task / ambient lighting best practice demonstrations. To develop practice designs and specifications for offices, laboratories, and hospitals. Scope of the demonstrations is large multi-regional demonstrations.

Existing research: Rensselaer Polytechnic Institute Lighting Research Center (LRC), National Renewable Energy Laboratory (NREL) Research Support Facility (RSF). Also Stanford University with Finelite.

- Subject matter experts referred to seven demonstration projects that are part of the LRC's Demonstration and Evaluation of Lighting Technologies and Applications (DELTA) program; see http://www.lrc.rpi.edu/programs/DELTA/index.asp.
- Stanford University's "Y2E2" campus building is "Finelite's High Performance, Energy Efficient Lighting Installed at Stanford University" that Finelight describes as the "greenest building on the Stanford campus and one that is making a dramatic statement in sustainable building and lighting." See http://www.finelite.com/about-us/success-stories.html.
- *[Summaries of other existing research pending]*

Key research questions:

1. Integrate task / ambient controls with HVAC.
2. Develop performance specifications to ensure optimal light quality and functionality while minimizing energy use?
3. Digital and DC power systems.
4. Integration with daylighting and fenestration, smart bi-level systems.
5. Integration with solar photovoltaic (PV) and renewable net zero energy (NZE) buildings.


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Task / Ambient Lighting (3 of 6)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Desire for individual control over lighting
Optimize human performance (health, productivity)
Desire for individual control over lighting
Energy security
Climate change
Optimize human performance (health, productivity)
Next generation lighting codes likely to be more focused on lighting performance
Optimize work environment for using computers of the future-keep up as computers evolve
Optimize human performance (health, productivity)
Lack of understanding user preferences related to individual control
Need for electric lighting that mimics the color intensity and variability of a new daylight space
Need to develop ability to quantify task lighting levels and reduce lighting energy consumption
Need to develop a standard practice to reduce ambient light levels while increasing use of task lighting
Need to develop better metrics to capture task / ambient for codes and actual energy performance
Modern "Tablets" are specular, leading to glare on work surface from light sources in room again
Need lighting controls and technology that can work together to create a more comfortable and tunable lighting environment
Lack of intelligence to support next generation codes standards programs
Technology to integrate task / ambient lighting with daylighting as a system
Task / ambient luminaires designs to provide spectral, spatial, and temporal lighting functions synergistically
Task /ambient controls to ensure energy savings relative to simply adding task lighting
Task / ambient need digital controls system integration and direct current powerlable
Define light levels for integrated office and classroom lighting in both ambient and task specific applications
Balanced luminous environment to avoid "cave effect"
Clarify performance metrics
Design standards applied to technologies
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

Design standards applied to technologies. The Illuminating Engineering Society (IES) is currently developing design for task and ambient lighting applications; apply these standards as they become available. For more information on these standards, see http://www.iesna.org/.

Existing research: None identified.

Key research questions:

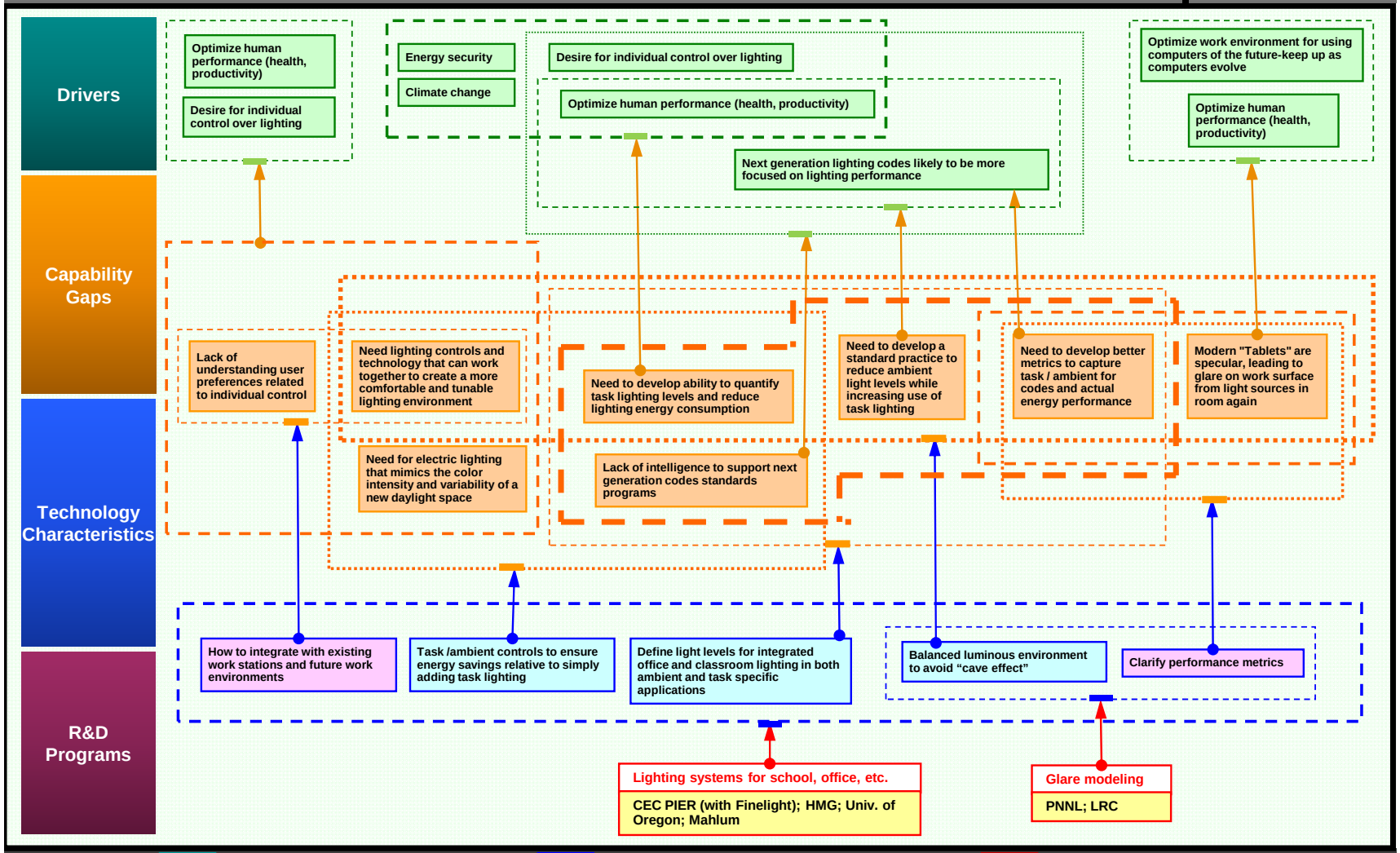
1. Are there any metrics (especially biometrics-pupil size, skin resistivity, eye movement toward ot away from light, hormonal or blood chemicals) that can be used as an indicator of better lighting with respect to end user comfort and satisfaction?
2. Can satisfaction metrics be tied to luminaire and control metrics independently and measured objectively ?
3. Can these luminaire metrics be used to qualify good lighting vs unacceptable lighting?

Product/Service Area : **LIGHTING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Task / Ambient Lighting (4 of 6)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Lighting systems for school, office, etc. Review research from existing programs that adopt Finelight's Integrated Classroom Lighting System (ICLS) (http://www.finelite.com/about-us/news/icls-integrated-classroom-lightingsystem.html) or Personal Lighting System (http://finelite.pinnaclecart.com/), and/or related systems, to maximize lighting effectiveness in offices and reduce the need for over-lighting.

Existing research: Research by the California Energy Commission (CEC) Public Interest Energy Research (PIER) program (with Finelight). The Heschong Mahone Group (HMG) is also working in this area. Mahlum and the University of Oregon's (UO) Energy Studies in Buildings Laboratory have conducted some studies on hospital lighting.

- In May 2007, Finelite, Inc., completed the CEC PIER study "Integrated Classroom Lighting System Final Report (CEC-500-2005-141-A14)" outlining the development and testing of an integrated classroom lighting system (ICLS) for K-12 classrooms (available at http://www.energy.ca.gov/pier/project_reports/CEC-500-2005-141-A14.html).
- HMG: (http://www.h-m-g.com/).
- Seattle design firm Mahlum (http://www.mahlum.com/) dedicated the inaugural issue of their Healthcare Design Insights periodical in Autumn 2009 to daylighting in hospitals, including providing basic guidelines and brief descriptions of some current research in this area (http://www.mahlum.com/pdf/MahlumHDIAutumn2009Issue01.pdf).
- The UO Energy Studies in Buildings Laboratory (http://aaa.uoregon.edu/esbl/) partnered with Zimmer Gunsul Frasca Architects (http://www.zgf.com/) in 2005 on a joint research study, "Daylighting Hospital Patient Rooms" (http://www.betterbricks.com/graphics/assets/documents/Daylighting_Patient_Rooms_brochure_final.pdf).

Key research questions:

1. Show student performance is improved in ICLS classrooms compared to control classrooms. Follow HMG methodology used for daylighting in classrooms. ICLS installs have hit number of installations where this number is possible.
2. Proprietary classroom systems for new installations and for retrofits include various feature groups. Which features are most important for energy savings and for student performance?
3. Develop low-cost systems for classroom retrofits.

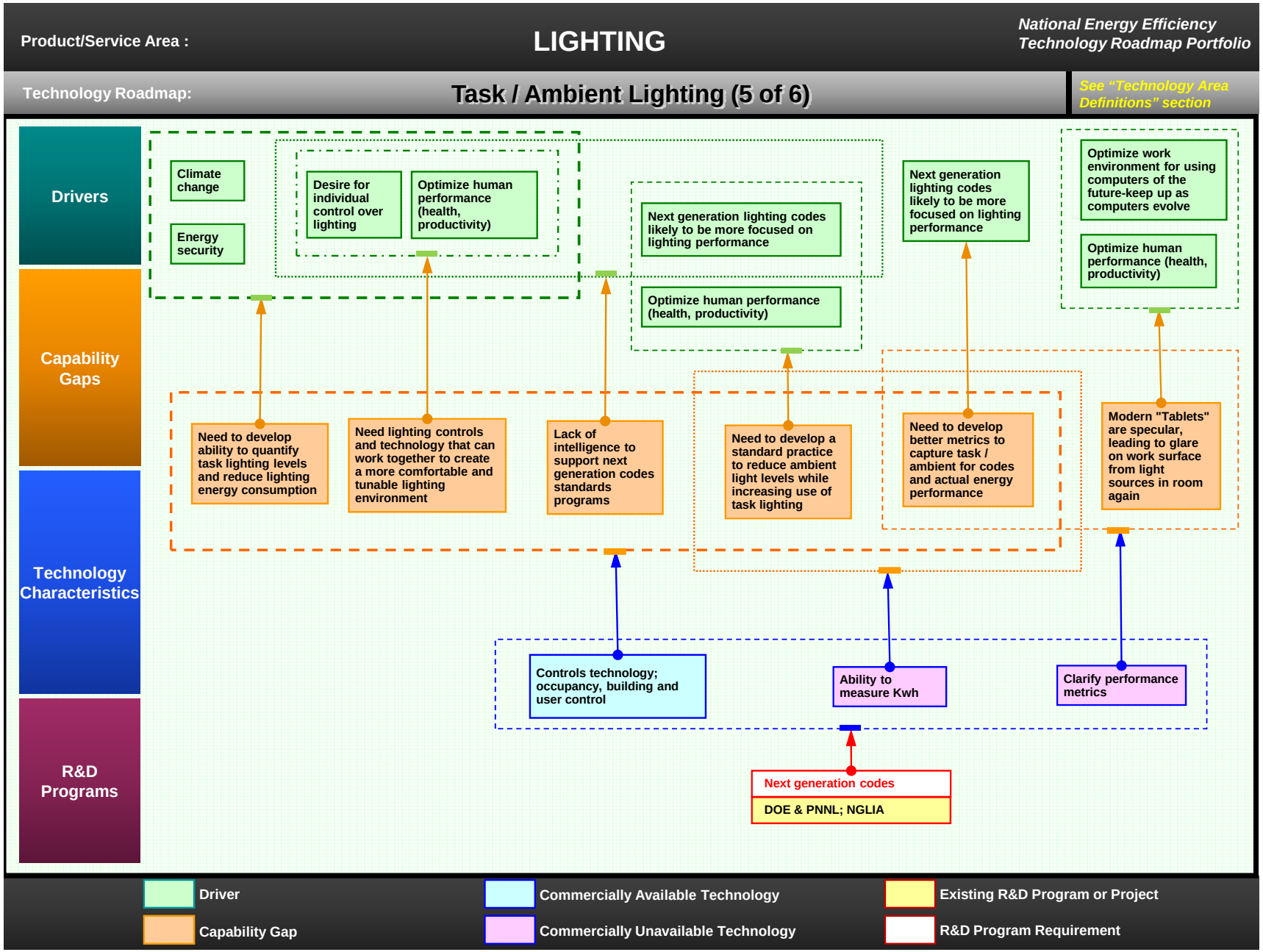
Glare modeling. Better understanding of glare mechanisms models and standards that support high quality visual environments.

Existing research: Pacific Northwest National Laboratory (PNNL), Rensselaer Polytechnic Institute Lighting Research Center (LRC).

- *[Summaries of existing research pending]*

Key research questions:

1. What are the existing glare models and deficiencies?
2. How does task ambient lighting impact glare?
3. What kinds of optics can mitigate glare?
4. How have visual tasks changed over the decades, and what are best practices to update historic lighting systems for today's tasks?
5. How do we change current building standards to adopt new glare models?
6. How do we teach design community to recognize glare as an issue?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Task / Ambient Lighting (5 of 6)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Climate change
Energy security
Desire for individual control over lighting
Optimize human performance (health, productivity)
Next generation lighting codes likely to be more focused on lighting performance
Optimize human performance (health, productivity)
Next generation lighting codes likely to be more focused on lighting performance
Optimize work environment for using computers of the future-keep up as computers evolve
Optimize human performance (health, productivity)
Need to develop ability to quantify task lighting levels and reduce lighting energy consumption
Need lighting controls and technology that can work together to create a more comfortable and tunable lighting environment
Lack of intelligence to support next generation codes standards programs
Need to develop a standard practice to reduce ambient light levels while increasing use of task lighting
Need to develop better metrics to capture task / ambient for codes and actual energy performance
Modern "Tablets" are specular, leading to glare on work surface from light sources in room again
Controls technology; occupancy, building and user control
Ability to measure Kwh
Clarify performance metrics
Next generation codes
DOE & PNNL; NGLIA
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

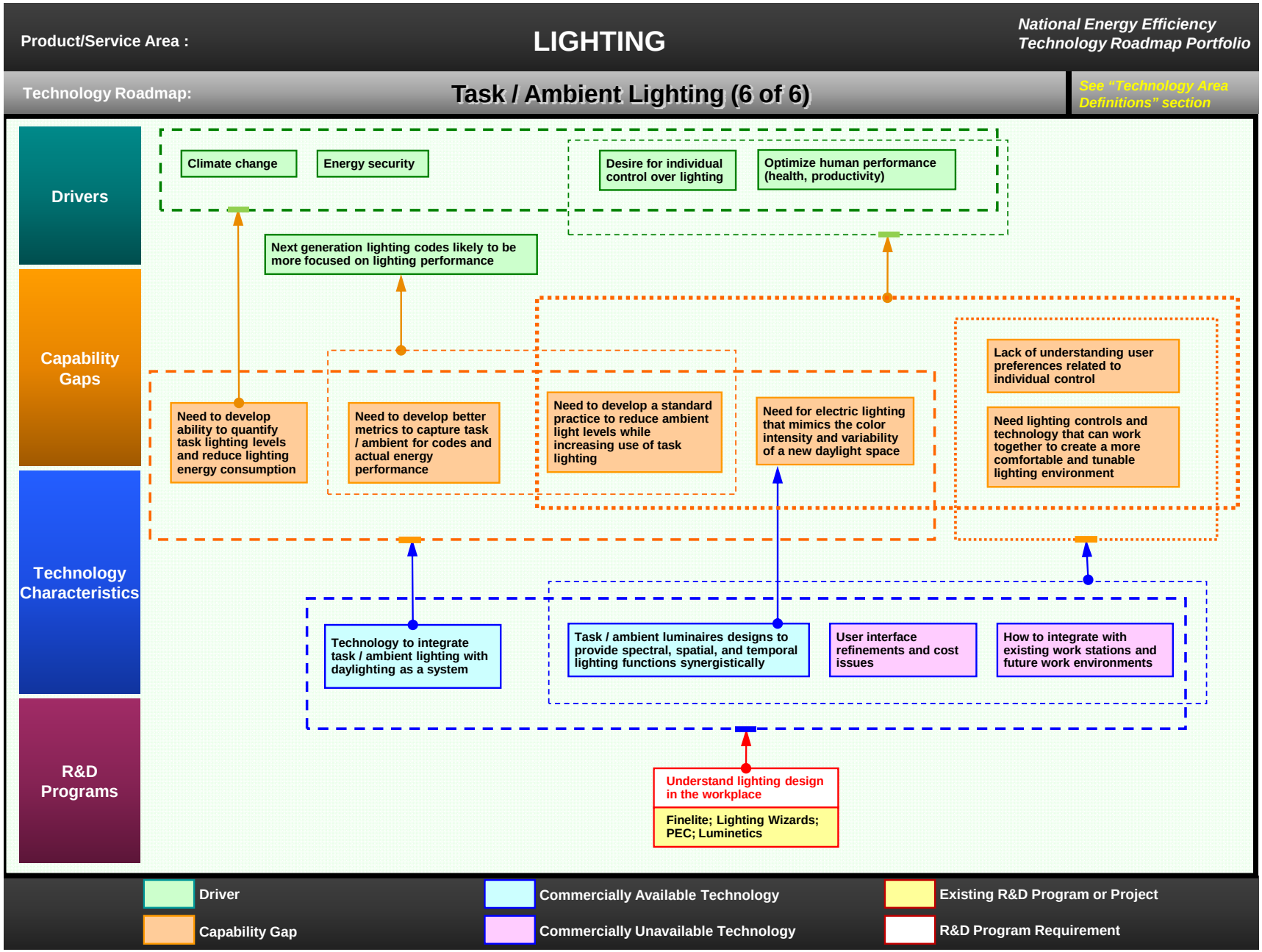
Next generation codes. Demonstrate savings and cost effectiveness of Task / Ambient lighting to support next generation codes.

Existing research: Subject matter experts referred to collaborative work among the U.S. Department of Energy (DOE) and the Pacific Northwest National Laboratory (PNNL), as well as the Next Generation Lighting Industry Alliance (NGLIA).

- *[Summaries of existing research pending]*

Key research questions:

1. Do current American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standards reflect future lighting practices?
2. How do we successfully integrate task / ambient approaches into national and state codes?
3. How do we best promote modern design practices that reflect task / ambient lighting?
4. How do we best use demonstrations to inform community to adopt this practice?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Task / Ambient Lighting (6 of 6)
See "Technology Area Definitions" section
Drivers
Climate change
Energy security
Desire for individual control over lighting
Optimize human performance (health, productivity)
Capability Gaps
Next generation lighting codes likely to be more focused on lighting performance
Need to develop ability to quantify task lighting levels and reduce lighting energy consumption
Need to develop better metrics to capture task / ambient for codes and actual energy performance
Need to develop a standard practice to reduce ambient light levels while increasing use of task lighting
Need for electric lighting that mimics the color intensity and variability of a new daylight space
Lack of understanding user preferences related to individual control
Need lighting controls and technology that can work together to create a more comfortable and tunable lighting environment
Technology Characteristics
Technology to integrate task / ambient lighting with daylighting as a system
Task / ambient luminaires designs to provide spectral, spatial, and temporal lighting functions synergistically
User interface refinements and cost issues
How to integrate with existing work stations and future work environments
R&D Programs
Understand lighting design in the workplace
Finelite; Lighting Wizards; PEC; Luminetics
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

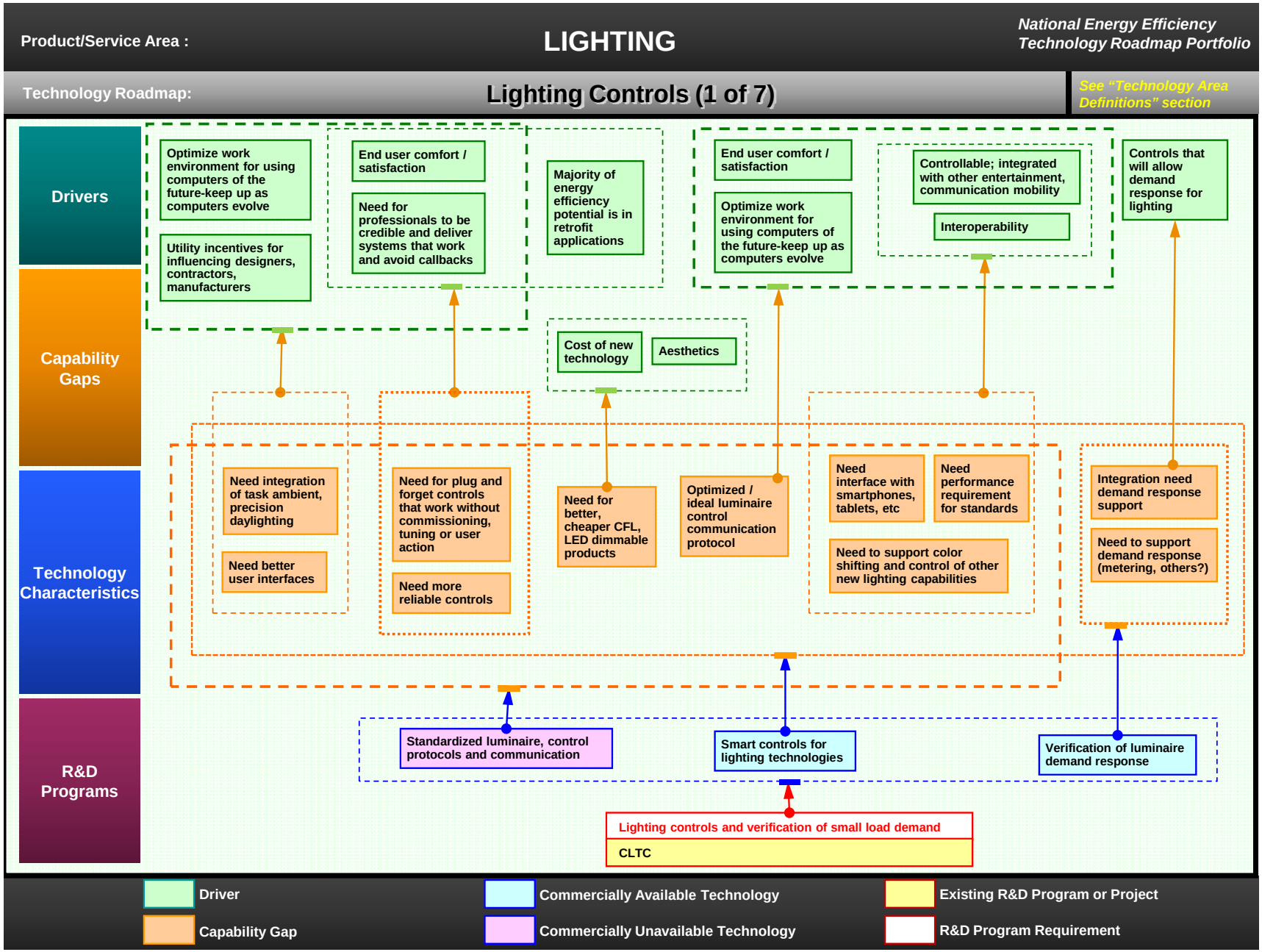
Understand lighting design in the workplace. (Summary not yet provided.)

Existing research: Finelite, Lighting Wizards, Pacific Energy Center (PEC), Luminetics.

- Subject matter experts referenced the work of Stan Walerczyk at Lighting Wizards (http://lightingwizards.com/).
- *[Summaries of existing research pending]*

Key research questions:

1. What will be the evolving workplace of the future?
2. What are the requirements for human interface with lighting layers?
3. How to execute future lighting design using 250,000 lighting hour technology?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Lighting Controls (1 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Optimize work environment for using computers of the future-keep up as computers evolve
Utility incentives for influencing designers, contractors, manufacturers
End user comfort / satisfaction
Need for professionals to be credible and deliver systems that work and avoid callbacks
Majority of energy efficiency potential is in retrofit applications
End user comfort / satisfaction
Optimize work environment for using computers of the future-keep up as computers evolve
Controllable; integrated with other entertainment, communication mobility
Interoperability
Controls that will allow demand response for lighting
Cost of new technology
Aesthetics
Need integration of task ambient, precision daylighting
Need better user interfaces
Need for plug and forget controls that work without commissioning, tuning or user action
Need more reliable controls
Need for better, cheaper CFL, LED dimmable products
Optimized / ideal luminaire control communication protocol
Need interface with smartphones, tablets, etc
Need performance requirement for standards
Need to support color shifting and control of other new lighting capabilities
Integration need demand response support
Need to support demand response (metering, others?)
Standardized luminaire, control protocols and communication
Smart controls for lighting technologies
Verification of luminaire demand response
Lighting controls and verification of small load demand
CLTC
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Lighting controls and verification of small load demand. Provide research to quantify magnitude of demand response (DR) associated with lighting modification relative to DR call or event.

Existing research: University of California Davis California Lighting Technology Center (CLTC).

- *Summaries of existing research pending]*

Key research questions:

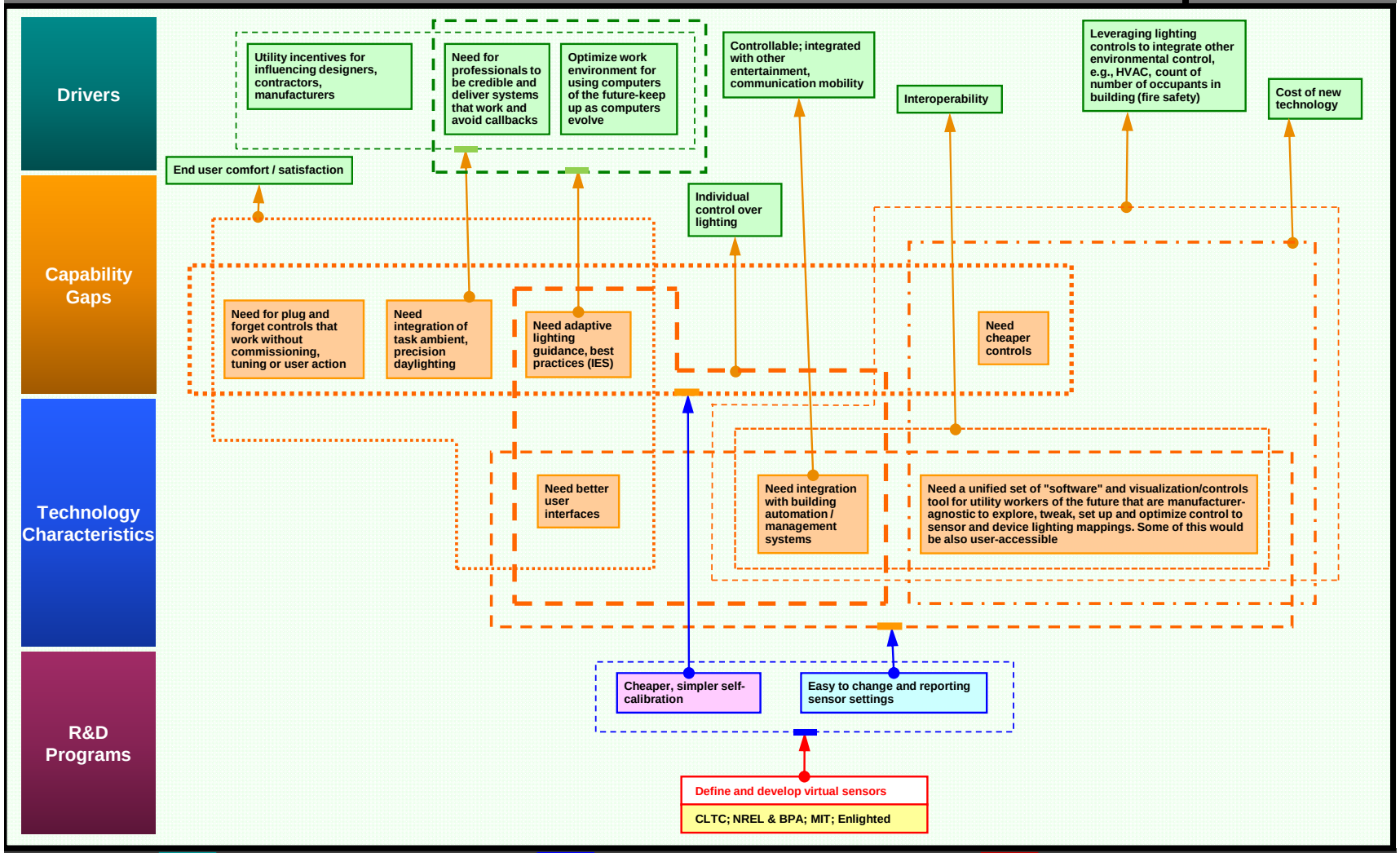
1. In response to a DR event, quantify and report amount of demand directly associated with DR call provided by lighting.
2. Define standard methodology for command, control and data exchange between lighting control systems and supplier?

Product/Service Area : **LIGHTING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Lighting Controls (2 of 7)**

See "Technology Area Definitions" section



Driver | Commercially Available Technology | Existing R&D Program or Project

Capability Gap | Commercially Unavailable Technology | R&D Program Requirement

R&D Program Summaries

Define and develop virtual sensors. Some controls try to adjust settings according to the habits of the user. Cheaper, simpler, and more effective ways of doing this will be helpful. This will likely take advantage of better predictive modeling.

Existing research: Massachusetts Institute of Technology's (MIT), National Renewable Energy Laboratory (NREL) with the Bonneville Power Administration (BPA), Enlighted, University of California Davis California Lighting Technology Center (CLTC).

- The MIT Media Lab is currently researching feedback controlled solid state lighting, with a specific focus on low-cost solutions that sense and respond to human factors including user context, circadian rhythms, and productivity, and integrating these responses with atypical environmental factors. See Appendix B for more information.
- NREL is working on a project funded by the BPA Technology Innovation (TI) Office to develop an enhanced Image Processing Occupancy Sensor (IPOS) prototype. This is BPA TI Project #247, "Image Processing Occupancy Sensor (IPOS) Prototype Enhancement and Testing"; see Appendix B for more information.
- Enlighted (enlightedinc.com).
- *[Summaries of other existing research pending]*

Key research questions:

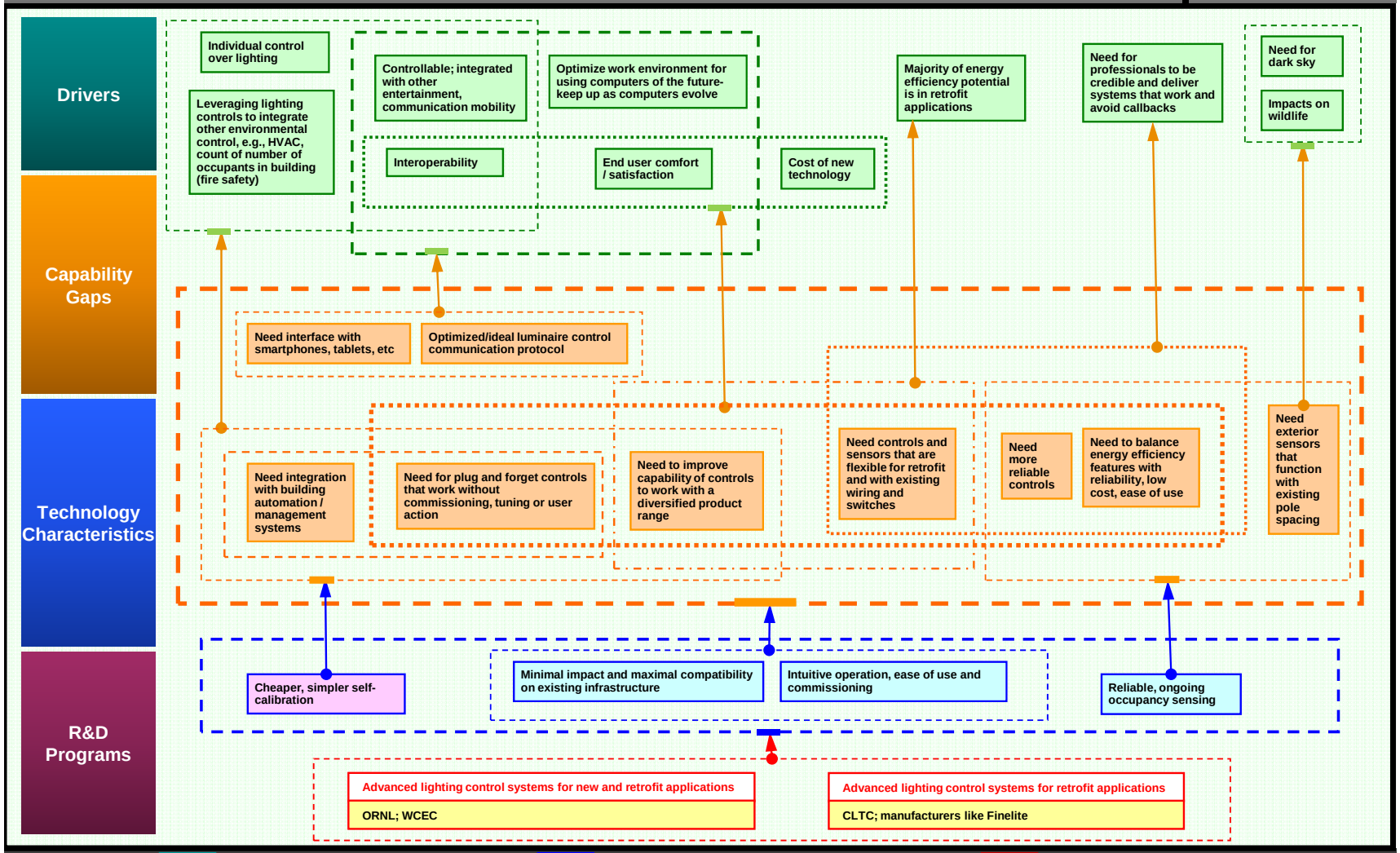
1. Determine/identify space characterization needs above and beyond basic occupancy.
2. Generate higher level sensor data to mitigate identified capability gaps. Example: use occupancy sensor and camera data to produce "traffic" information.
3. How to extract general context from virtual sensor data?
4. Develop self-commissioning systems for plug-and-play installation.

Product/Service Area : **LIGHTING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Lighting Controls (3 of 7)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Advanced lighting control systems for retrofit applications. Leverage existing infrastructure (or legacy building system) rather than having to undertake a major retrofit/upgrade.

Existing research: University of California Davis California Lighting Technology Center (CLTC), Finelight.

- *[Summaries of existing research pending]*

Key research questions:

1. How do the advanced systems for retrofit tie into existing infrastructure?
2. What is the cost energy savings vs. energy left on the table comparisons?

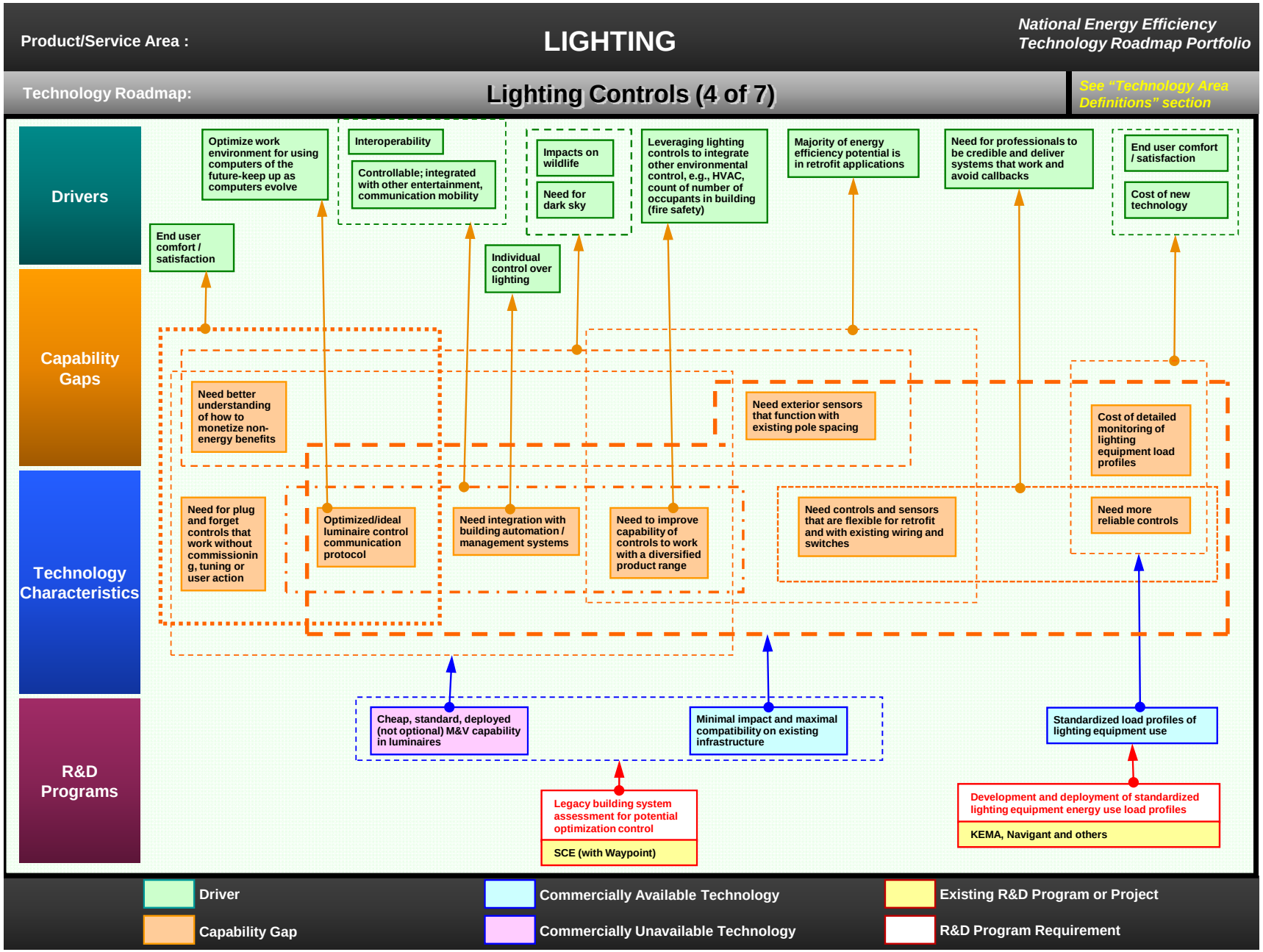
Advanced lighting control systems for new and retrofit applications. (Summary not yet provided).

Existing research: Oak Ridge National Laboratory (ORNL), University of California Davis Western Cooling Efficiency Center (WCEC).

- For ORNL's research, see Appendix B.
- For WCEC's research integrating HVAC, lighting, and other controls, see Appendix B.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Lighting Controls (4 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Optimize work environment for using computers of the future-keep up as computers evolve
Interoperability
Controllable; integrated with other entertainment, communication mobility
Impacts on wildlife
Need for dark sky
Leveraging lighting controls to integrate other environmental control, e.g., HVAC, count of number of occupants in building (fire safety)
Majority of energy efficiency potential is in retrofit applications
Need for professionals to be credible and deliver systems that work and avoid callbacks
End user comfort / satisfaction
Cost of new technology
End user comfort / satisfaction
Individual control over lighting
Need better understanding of how to monetize non-energy benefits
Need exterior sensors that function with existing pole spacing
Cost of detailed monitoring of lighting equipment load profiles
Need for plug and forget controls that work without commissioning, tuning or user action
Optimized/ideal luminaire control communication protocol
Need integration with building automation / management systems
Need to improve capability of controls to work with a diversified product range
Need controls and sensors that are flexible for retrofit and with existing wiring and switches
Need more reliable controls
Cheap, standard, deployed (not optional) M&V capability in luminaires
Minimal impact and maximal compatibility on existing infrastructure
Standardized load profiles of lighting equipment use
Legacy building system assessment for potential optimization control
SCE (with Waypoint)
Development and deployment of standardized lighting equipment energy use load profiles
KEMA, Navigant and others
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Development and deployment of standardized equipment profiles. The capabilities of luminaires and control "widgets" can be best leveraged by systems that fully understand their capabilities. A standardized way for widgets to communicate this capability needs to be identified and developed.

Existing research: KEMA, Navigant, and others as part of technical reference manual (TRM) / work paper development.

- *[Summaries of existing research pending]*

Key research questions:

1. How should luminaires describe their capabilities?
2. How should control, sensor widgets describe their capabilities?
3. What information should be stored in the widget? Actual data or Internet hyperlink to download data?
4. Does new two-way communication protocol to be integrated into drivers ballast need to be developed?

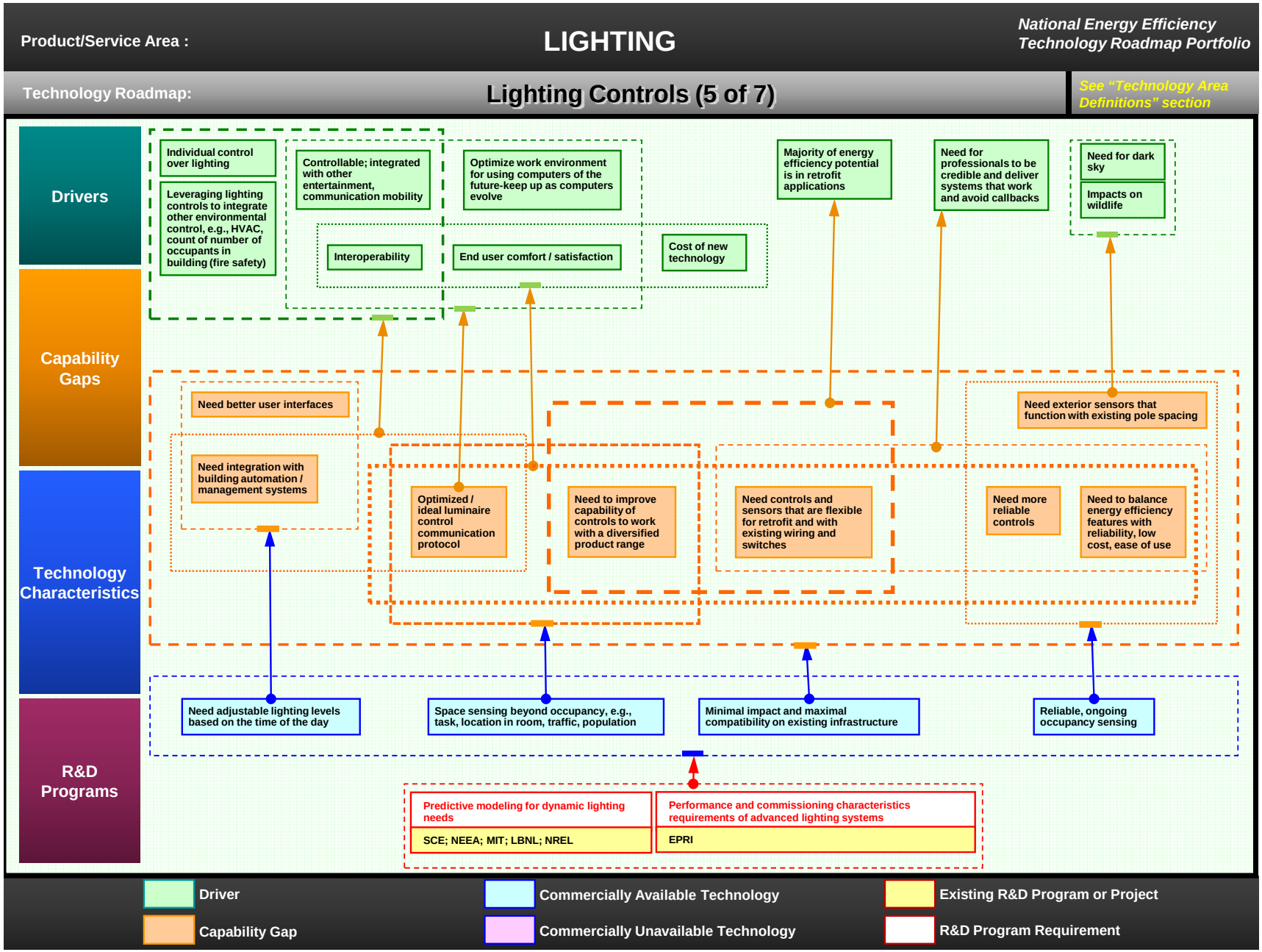
Legacy building system assessment for potential optimization control. The goal of this program would be to evaluate and assess existing and often proprietary building systems to determine the technical and cost effectiveness of revitalizing legacy systems and interface with newer sensors.

Existing research: Southern California Edison (SCE) with Waypoint.

- *[Summaries of existing research pending]*

Key research questions:

1. Identify popular legacy systems and evaluate their existing utilization.
2. Identify appropriate "matching" technology that is able to leverage and augment existing legacy system.
3. Determine cost-benefit or cost effectiveness of rip and replace Vs. utilizing some parts or all of the legacy system.


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Lighting Controls (5 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Individual control over lighting
Leveraging lighting controls to integrate other environmental control, e.g., HVAC, count of number of occupants in building (fire safety)
Controllable; integrated with other entertainment, communication mobility
Optimize work environment for using computers of the future-keep up as computers evolve
Interoperability
End user comfort / satisfaction
Cost of new technology
Majority of energy efficiency potential is in retrofit applications
Need for professionals to be credible and deliver systems that work and avoid callbacks
Need for dark sky
Impacts on wildlife
Need better user interfaces
Need integration with building automation / management systems
Optimized / ideal luminaire control communication protocol
Need to improve capability of controls to work with a diversified product range
Need controls and sensors that are flexible for retrofit and with existing wiring and switches
Need exterior sensors that function with existing pole spacing
Need more reliable controls
Need to balance energy efficiency features with reliability, low cost, ease of use
Need adjustable lighting levels based on the time of the day
Space sensing beyond occupancy, e.g., task, location in room, traffic, population
Minimal impact and maximal compatibility on existing infrastructure
Reliable, ongoing occupancy sensing
Predictive modeling for dynamic lighting needs
SCE; NEEA; MIT; LBNL; NREL
Performance and commissioning characteristics requirements of advanced lighting systems
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Performance and commissioning characteristics requirements of advanced lighting systems. Ties back to research project on failed controls installations and learning what not to do, developing performance standards and using these standards to assess lighting systems.

Existing research: Electric Power Research Institute (EPRI).

- For EPRI research in this area, see Appendix B.

Key research questions:

1. What are the steps needed to develop assessment protocols? Are there any protocols in place today?
2. How can assessment tools be integrated as part of user controls?

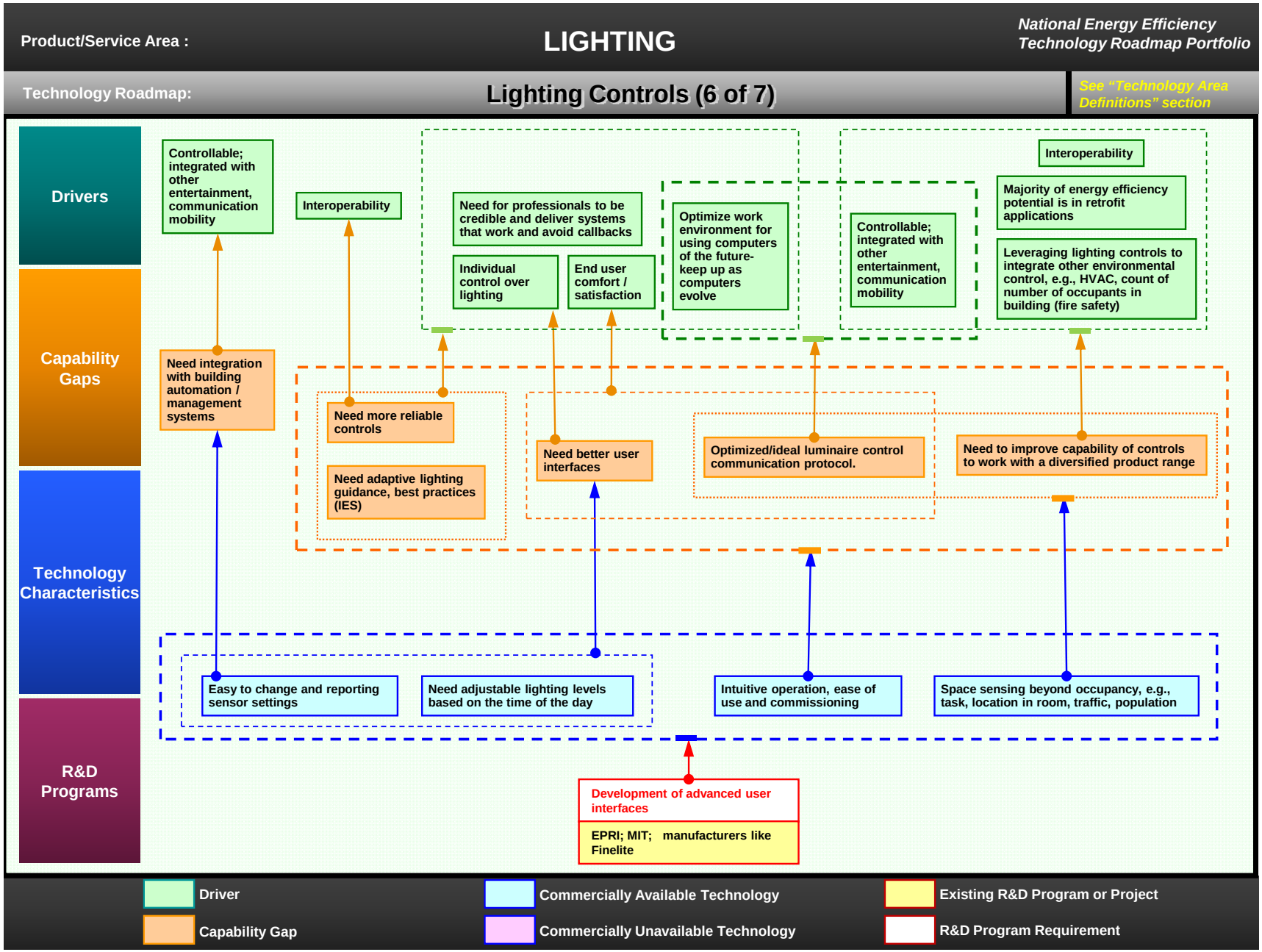
Predictive modeling for dynamic lighting needs. Research on modeling that will better predict lighting needs by taking into account the time of day and day of the week will make lighting controls more useful and more acceptable to users. Likely using predictive modeling developed from research being done at Massachusetts Institute of Technology's (MIT) Media Lab and possibly other institutions, integrate controls that predict lighting needs dynamically by taking into account the time of day and day of the week for the user will make lighting controls more useful and more acceptable to users.

Existing research: Researchers at Massachusetts Institute of Technology's (MIT) Media Lab, the University of California Davis California Lighting Technology Center (CLTC), the Lawrence Berkeley National Laboratory (LBNL), the Northwest Energy Efficiency Alliance (NEEA), and Southern California Edison (SCE) are among those doing work in this area. Subject matter experts have also indicated that R&D in this area may be ongoing at Watt Stopper and/or Lithonia Lighting..

- The MIT Media Lab is currently researching feedback controlled solid state lighting, with a specific focus on low-cost solutions that sense and respond to human factors including user context, circadian rhythms, and productivity, and integrating these responses with atypical environmental factors. See Appendix B for more information.
- Lithonia Lighting: http://www.lithonia.com/.
- CLTC work in this area includes researching exterior occupancy sensor networks to predict the direction and speed of pedestrians, cyclists and vehicles.
- For LBNL's research, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. How can predictive modeling for dynamic lighting needs help to create simpler calibration of systems?
2. When it comes to occupancy sensing, are we detecting people in the most optimal method?
3. How can spaces use knowledge of :
   a. Available luminaires?
   b. Available sensors?
   c. Pre-informed or determined via calibration) to produce optimal illumination automatically?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Lighting Controls (6 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Controllable; integrated with other entertainment, communication mobility
Interoperability
Need for professionals to be credible and deliver systems that work and avoid callbacks
Individual control over lighting
End user comfort / satisfaction
Optimize work environment for using computers of the future- keep up as computers evolve
Controllable; integrated with other entertainment, communication mobility
Interoperability
Majority of energy efficiency potential is in retrofit applications
Leveraging lighting controls to integrate other environmental control, e.g., HVAC, count of number of occupants in building (fire safety)
Need integration with building automation / management systems
Need more reliable controls
Need adaptive lighting guidance, best practices (IES)
Need better user interfaces
Optimized/ideal luminaire control communication protocol.
Need to improve capability of controls to work with a diversified product range
Easy to change and reporting sensor settings
Need adjustable lighting levels based on the time of the day
Intuitive operation, ease of use and commissioning
Space sensing beyond occupancy, e.g., task, location in room, traffic, population
Development of advanced user interfaces
EPRI; MIT; manufacturers like Finelite
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

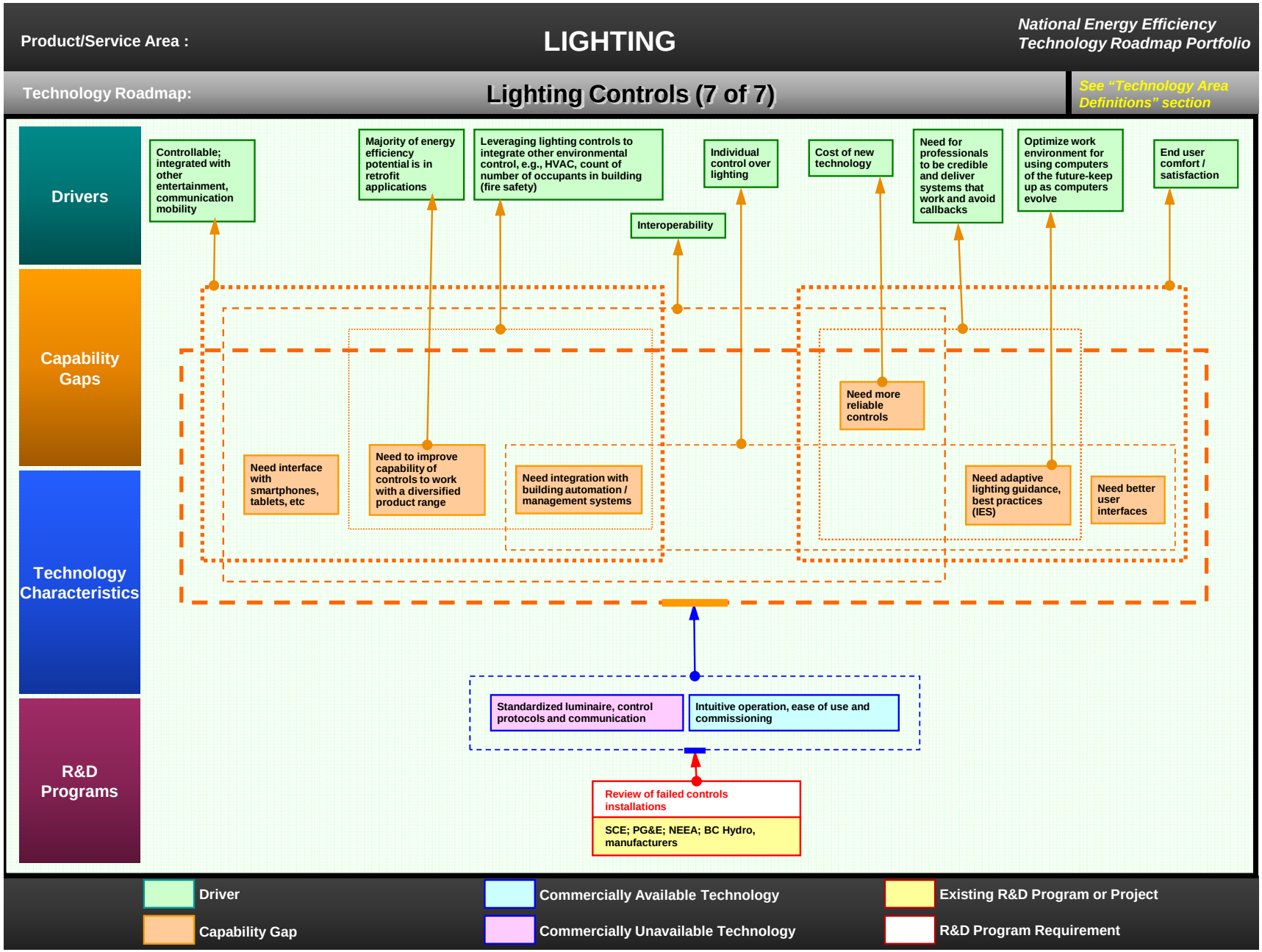
Development of advanced user interfaces. Develop methods that make controls intuitive and easy to use or transparent.

Existing research: Electric Power Research Institute (EPRI), Masachusetts Institute of Technology (MIT), manufacturers such as Finelight.

- For MIT's "Wristique" project, see Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. Behavior analysis—what are the best methods for users to interact with lighting controls?
2. Individual recognition—non intrusive recognition system.
3. Rule making protocol—what rules needed to address interactions and differing commands between users?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Lighting Controls (7 of 7)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Controllable; integrated with other entertainment, communication mobility
Majority of energy efficiency potential is in retrofit applications
Leveraging lighting controls to integrate other environmental control, e.g., HVAC, count of number of occupants in building (fire safety)
Interoperability
Individual control over lighting
Cost of new technology
Need for professionals to be credible and deliver systems that work and avoid callbacks
Optimize work environment for using computers of the future-keep up as computers evolve
End user comfort / satisfaction
Need interface with smartphones, tablets, etc
Need to improve capability of controls to work with a diversified product range
Need integration with building automation / management systems
Need more reliable controls
Need adaptive lighting guidance, best practices (IES)
Need better user interfaces
Standardized luminaire, control protocols and communication
Intuitive operation, ease of use and commissioning
Review of failed controls installations
SCE; PG&E; NEEA; BC Hydro, manufacturers
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

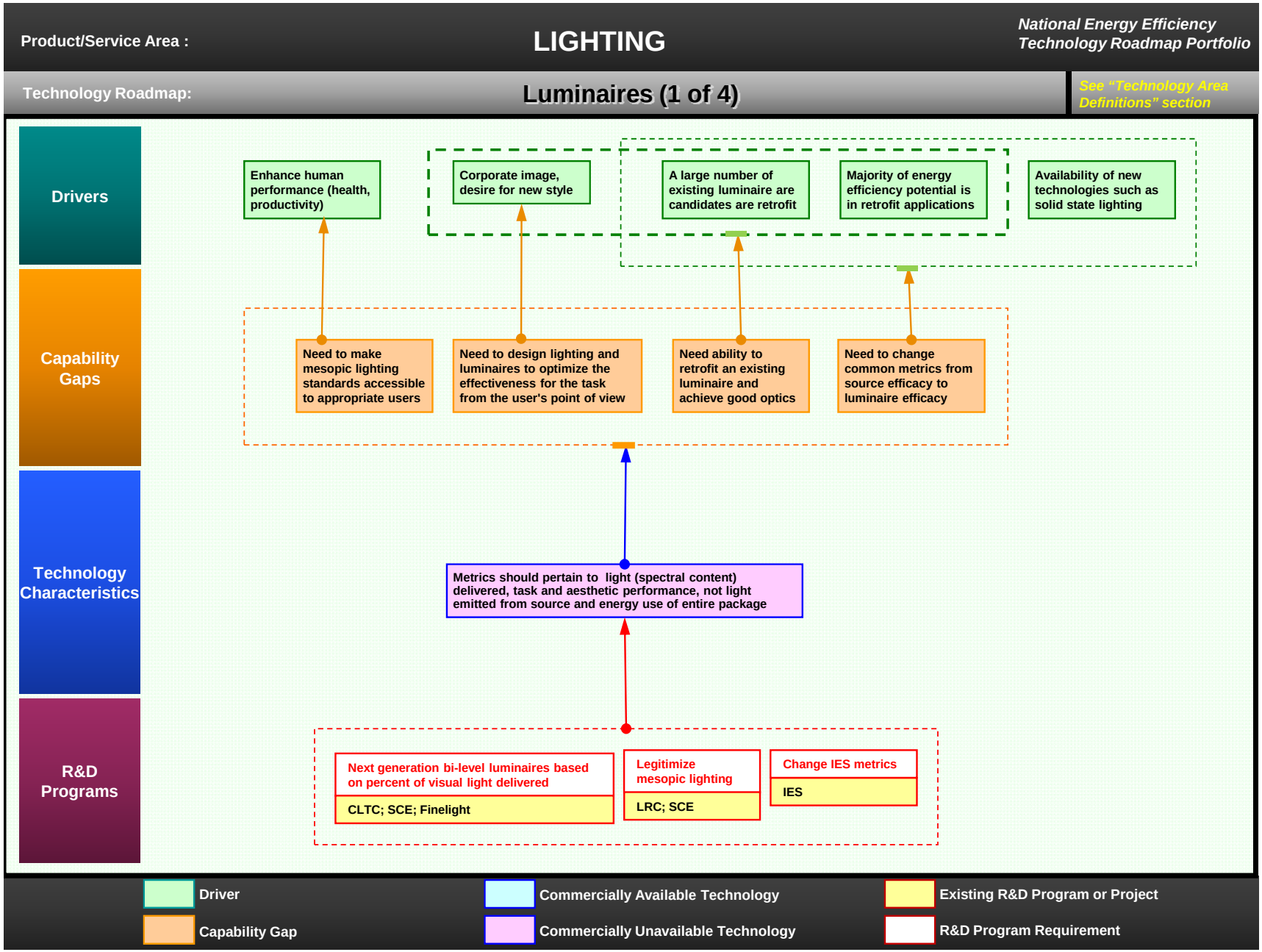
Review of failed controls installations. Review failed controls projects to learn what not to do to enable end user comfort and satisfaction. Leverage information to help develop performance standards for control systems.

Existing research: Southern California Edison (SCE), Pacific Gas & Electric (PG&E), Northwest Energy Efficiency Alliance (NEEA), BC Hydro, and manufacturers.

- *[Summaries of existing research pending]*

Key research questions:

1. How many failed controls projects are there?
2. Why did they fail?
3. What could have been done to prevent the failure?
4. How can this information be leveraged for technology?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Luminaires (1 of 4)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Enhance human performance (health, productivity)
Corporate image, desire for new style
A large number of existing luminaire are candidates are retrofit
Majority of energy efficiency potential is in retrofit applications
Availability of new technologies such as solid state lighting
Need to make mesopic lighting standards accessible to appropriate users
Need to design lighting and luminaires to optimize the effectiveness for the task from the user's point of view
Need ability to retrofit an existing luminaire and achieve good optics
Need to change common metrics from source efficacy to luminaire efficacy
Metrics should pertain to light (spectral content) delivered, task and aesthetic performance, not light emitted from source and energy use of entire package
Next generation bi-level luminaires based on percent of visual light delivered
CLTC; SCE; Finelight
Legitimize mesopic lighting
LRC; SCE
Change IES metrics
IES
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Legitimize mesopic lighting. Mesopic lighting, to be fully accepted by the market, needs to have standards changed to legitimize it. Provide data to support Illuminating Engineering Society (IES) standards modifications.

Existing research: Rensselaer Polytechnic Institute Lighting Research Center (LRC), Southern California Edison (SCE).

- An overview of LRC's mesopic lighting research can be found in Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. Questions not yet specified.

Change Illuminating Engineering Society (IES) metrics. Metrics and standards have evolved as we learn more about how humans use light most effectively. More work needs to be done to continue to improve Illuminating Engineering Society (IES) metrics.

Existing research: Illuminating Engineering Society (IES) .

- IES: http://www.iesna.org/.

Key research questions:

1. Questions not yet specified.

Next generation bi-level luminaires based on percent of visual light delivered. Determine if 15% light-level is sufficient for non-occupied stairwells and corridors. 15% is estimate of lowest "acceptable" light-level combined with lowest-cost / easiest to deliver light level. Research could set a different level.

Existing research: University of California Davis California Lighting Technology Center (CLTC), Southern California Edison (SCE), Finelight.

- *[Summaries of existing research pending]*

Key research questions:

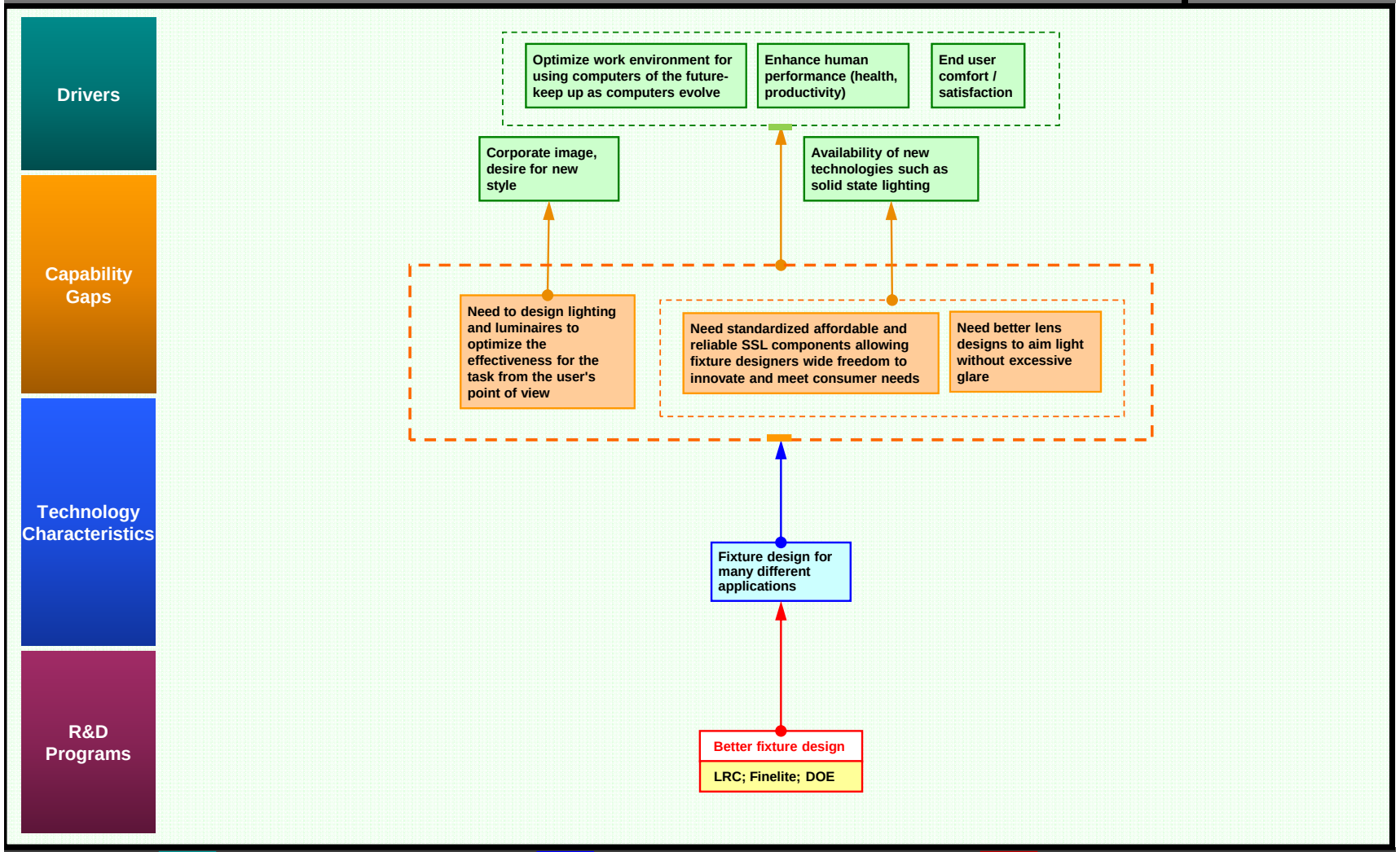
1. Will people accept a "bi-level" stairwell and corridor lighting approach where occupancy motion = 100%light level non occupancy no-motion = 15% light level? If so, SSI luminaires should need only 3% - 5% power when space is not occupied.
2. Integrate this research with fire code requirements.

Product/Service Area : **LIGHTING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Luminaires (2 of 4)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

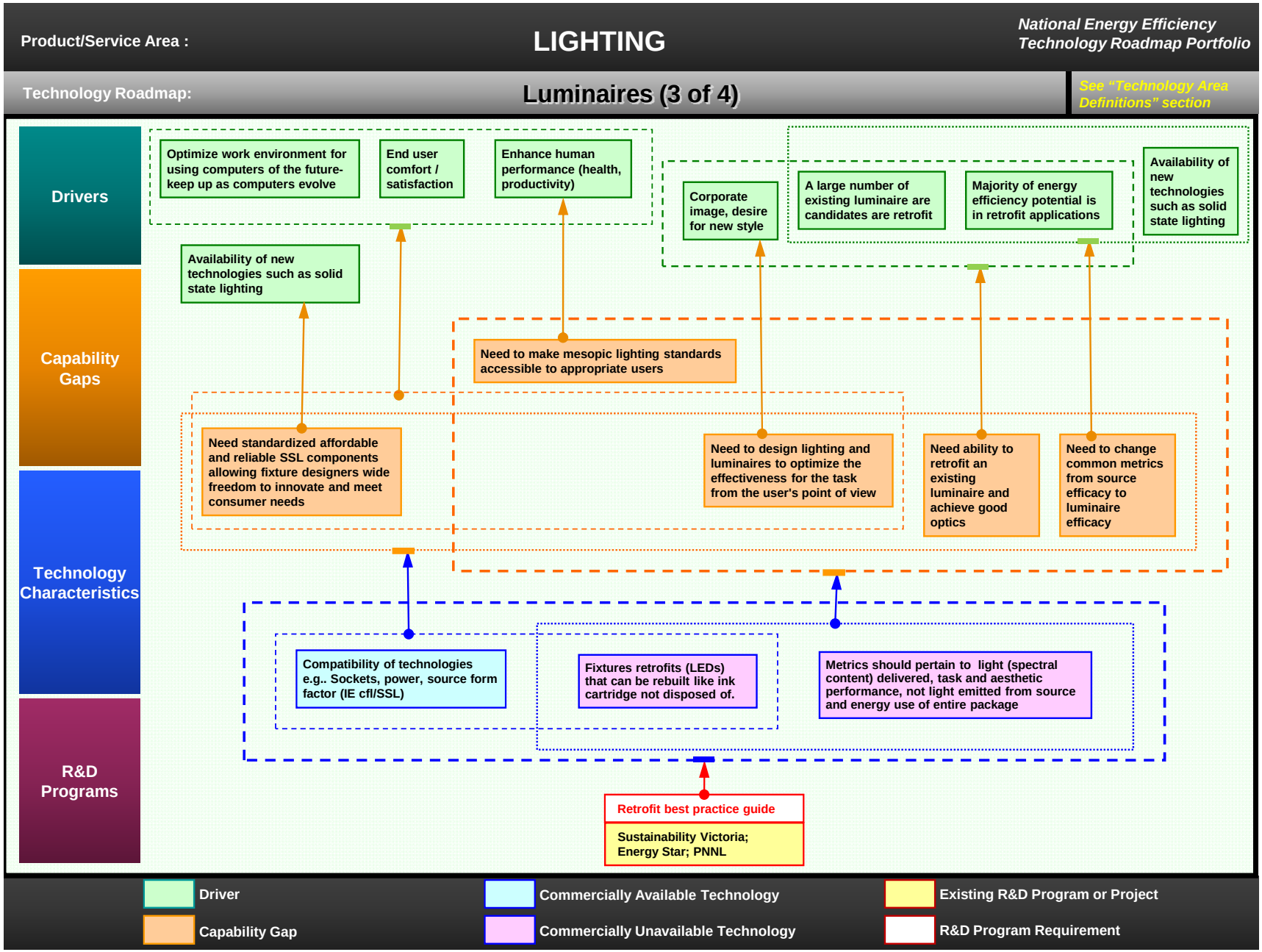
Better fixture design. Designing luminaires that take best advantage of solid state lighting (SSL) characteristics rather than look like traditional fixtures leads to the best performance. Dealing with replacement parts for premature failure is an issue. Lack of interchangeability will hamper the market.

Existing research: Many luminaire manufacturers are researching this issue, as is Finelight, the Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), and the Rensselaer Polytechnic Institute Lighting Research Center (LRC).

- More information about LRC's research can be found in Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. Questions not yet specified.


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Luminaires (3 of 4)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Optimize work environment for using computers of the future- keep up as computers evolve
End user comfort / satisfaction
Enhance human performance (health, productivity)
Corporate image, desire for new style
A large number of existing luminaire are candidates are retrofit
Majority of energy efficiency potential is in retrofit applications
Availability of new technologies such as solid state lighting
Availability of new technologies such as solid state lighting
Need to make mesopic lighting standards accessible to appropriate users
Need standardized affordable and reliable SSL components allowing fixture designers wide freedom to innovate and meet consumer needs
Need to design lighting and luminaires to optimize the effectiveness for the task from the user's point of view
Need ability to retrofit an existing luminaire and achieve good optics
Need to change common metrics from source efficacy to luminaire efficacy
Compatibility of technologies e.g.. Sockets, power, source form factor (IE cfl/SSL)
Fixtures retrofits (LEDs) that can be rebuilt like ink cartridge not disposed of.
Metrics should pertain to light (spectral content) delivered, task and aesthetic performance, not light emitted from source and energy use of entire package
Retrofit best practice guide
Sustainability Victoria; Energy Star; PNNL
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

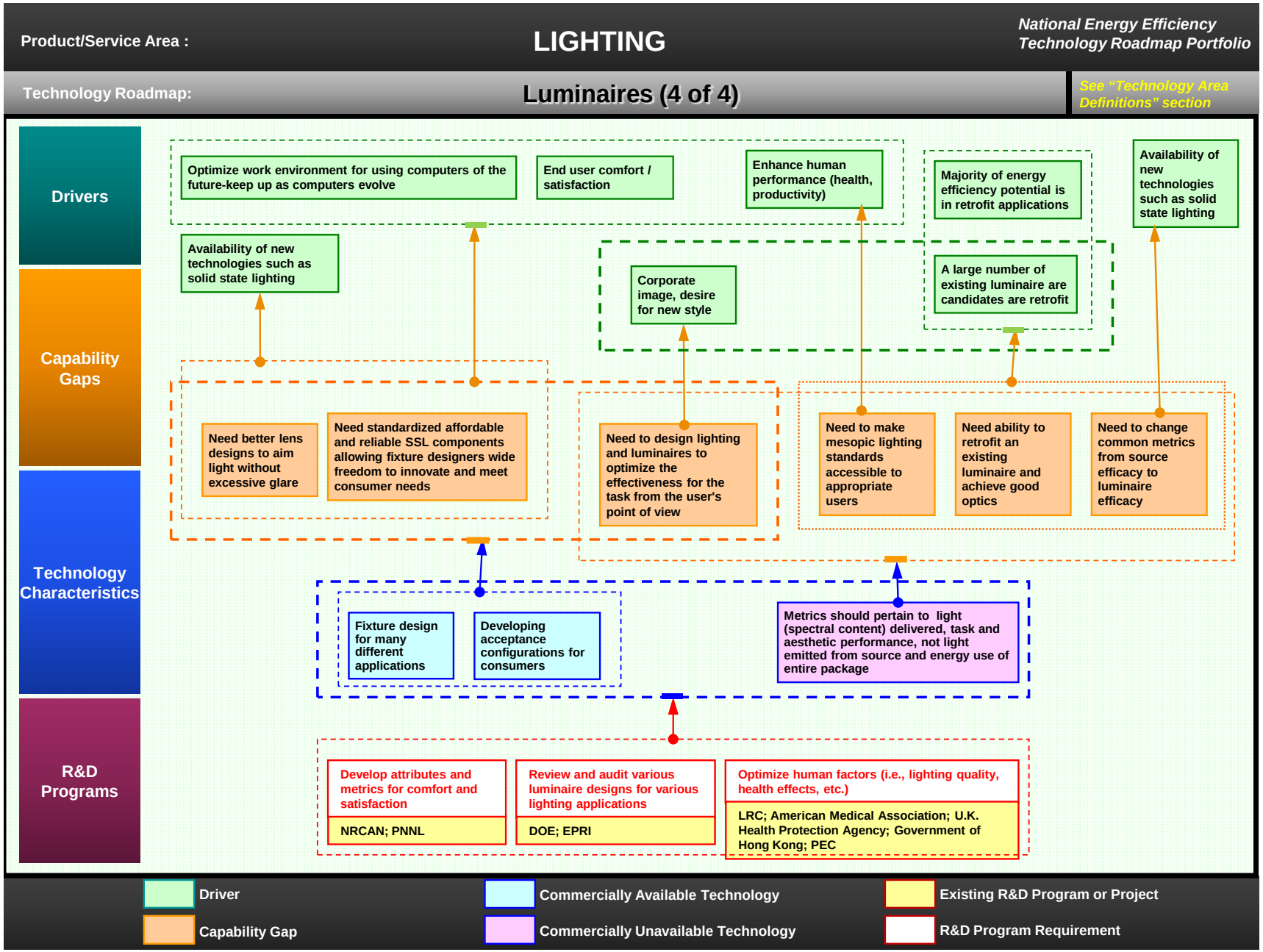
Retrofit best practice guide. Methodology for designing whether to replace luminaires, relamp, or retrofit components decision tree (flow chart).

Existing research: Sustainability Victoria, Energy Star, Pacific Northwest National Laboratory (PNNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Key performance criteria.
2. What to do, when to do it, how to do it?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Luminaires (4 of 4)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Optimize work environment for using computers of the future-keep up as computers evolve
End user comfort / satisfaction
Enhance human performance (health, productivity)
Majority of energy efficiency potential is in retrofit applications
Availability of new technologies such as solid state lighting
Availability of new technologies such as solid state lighting
Corporate image, desire for new style
A large number of existing luminaire are candidates are retrofit
Need better lens designs to aim light without excessive glare
Need standardized affordable and reliable SSL components allowing fixture designers wide freedom to innovate and meet consumer needs
Need to design lighting and luminaires to optimize the effectiveness for the task from the user's point of view
Need to make mesopic lighting standards accessible to appropriate users
Need ability to retrofit an existing luminaire and achieve good optics
Need to change common metrics from source efficacy to luminaire efficacy
Fixture design for many different applications
Developing acceptance configurations for consumers
Metrics should pertain to light (spectral content) delivered, task and aesthetic performance, not light emitted from source and energy use of entire package
Develop attributes and metrics for comfort and satisfaction
NRCAN; PNNL
Review and audit various luminaire designs for various lighting applications
DOE; EPRI
Optimize human factors (i.e., lighting quality, health effects, etc.)
LRC; American Medical Association; U.K. Health Protection Agency; Government of Hong Kong; PEC
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Review and audit various luminaire designs for various lighting applications. The importance of luminaires has often been overlooked in specifications and codes. Need to rate luminaires so better data are available, and then educate architects and designers on which luminaires to use for which applications to improve efficiency and effective lighting.

Existing research: The U.S. Department of Energy (DOE) has done work in this area, and the Electric Power Research Institute (EPRI) is as well.

- The DOE's Commercial Lighting Solutions provides tools in this area (https://www.lightingsolutions.energy.gov/comlighting/login.htm).
- For EPRI's research in this area, see Appendix B.

Key research questions:

1. Questions not yet specified.

Optimize human factors (i.e., lighting quality, health effects, etc.). Regardless of how efficient lighting is, it's only useful if it actually helps humans.

Existing research: Research on the relevant human factors is important and may apply to luminaires. Rensselaer Polytechnic Institute's Lighting Research Center (LRC) is doing much in this area. Others include the American Medical Association, the United Kingdom Health Protection Agency, the Government of Hong Kong, and the Pacific Energy Center (PEC).

- Appendix B provides an overview of LRC's research in this area. The LRC has upwards of sixty ongoing R&D projects at any given time, and a public list of R&D progress and final reports can be found at http://www.lrc.rpi.edu/resources/newsroom/projectsheets.asp.
- In addition to the projects identified above, the LRC also manages and updates the National Lighting Product Information Program (NLPIP, http://www.lrc.rpi.edu/programs/NLPIP/index.asp). This resource aids contractors, designers, building managers, homeowners, and others in identifying and using correctly the energy-efficient lighting solution that best fits their needs.
- *[Summaries of other existing research pending]*

Key research questions:

1. Questions not yet specified.

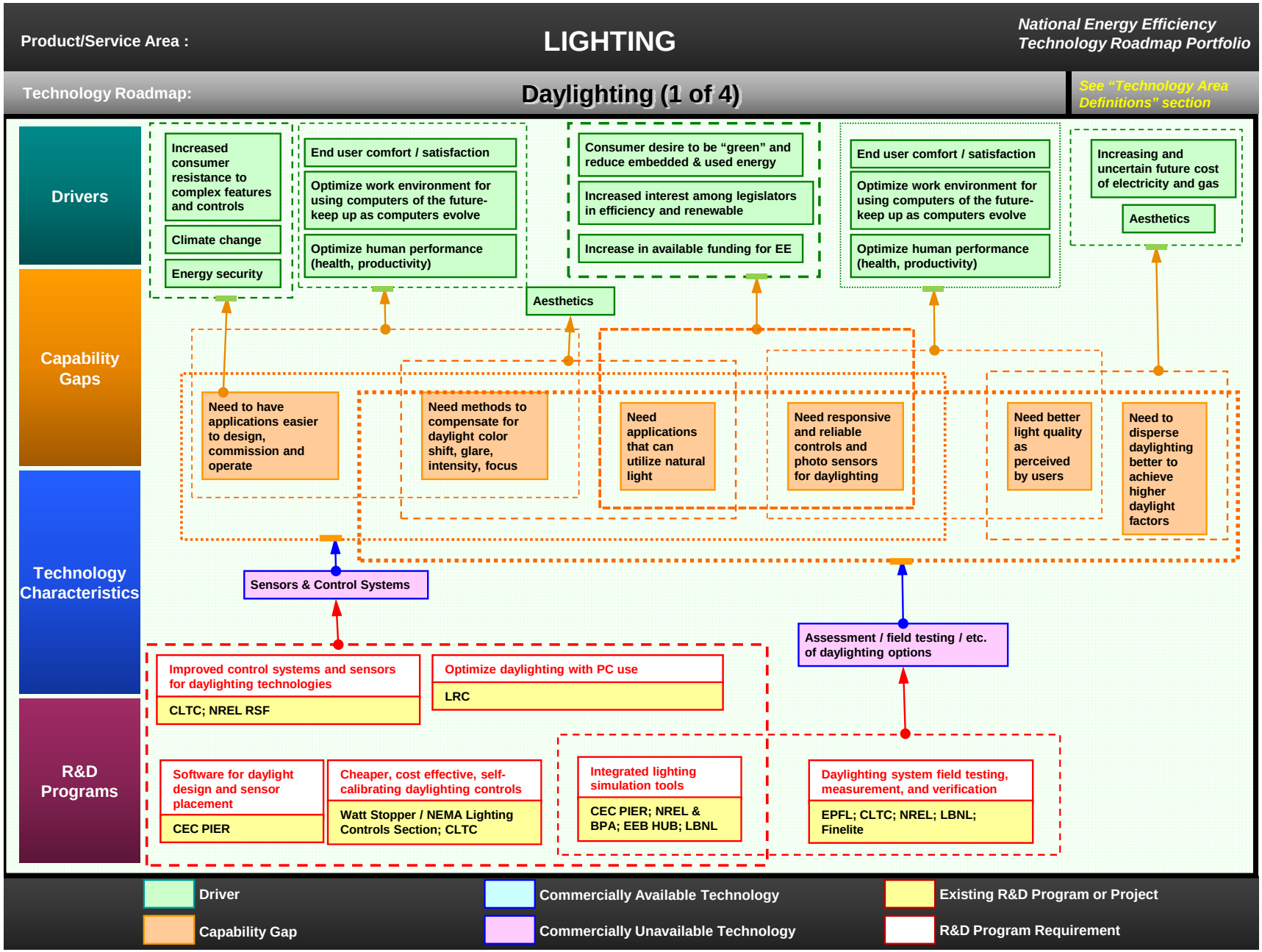
Develop attributes and metrics for comfort and satisfaction. Link to objective, measured luminaire parameters. Deliver per performance requisites for luminaires.

Existing research: NRCAN and PNNL.

- *[Summaries of existing research pending]*

Key research questions:

1. Is there any objective, repeatable biometrics that indicates increased user comfort / satisfaction?
2. Can this biometrics be linked to luminaire metrics that could be characterized in an independent test based on the Illumination Engineering Society (IES) LM-79 ("Approved Method: Electrical and Photometric Measurements of Solid-State Lighting Products")?
3. What are the product and performance attributes that drive consumer satisfaction and preference?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Daylighting (1 of 4)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Increased consumer resistance to complex features and controls
Climate change
Energy security
End user comfort / satisfaction
Optimize work environment for using computers of the future-keep up as computers evolve
Optimize human performance (health, productivity)
Consumer desire to be "green" and reduce embedded & used energy
Increased interest among legislators in efficiency and renewable
Increase in available funding for EE
End user comfort / satisfaction
Optimize work environment for using computers of the future-keep up as computers evolve
Optimize human performance (health, productivity)
Increasing and uncertain future cost of electricity and gas
Aesthetics
Aesthetics
Need to have applications easier to design, commission and operate
Need methods to compensate for daylight color shift, glare, intensity, focus
Need applications that can utilize natural light
Need responsive and reliable controls and photo sensors for daylighting
Need better light quality as perceived by users
Need to disperse daylighting better to achieve higher daylight factors
Sensors & Control Systems
Assessment / field testing / etc. of daylighting options
Improved control systems and sensors for daylighting technologies
CLTC; NREL RSF
Optimize daylighting with PC use
LRC
Software for daylight design and sensor placement
CEC PIER
Cheaper, cost effective, self-calibrating daylighting controls
Watt Stopper / NEMA Lighting Controls Section; CLTC
Integrated lighting simulation tools
CEC PIER; NREL & BPA; EEB HUB; LBNL
Daylighting system field testing, measurement, and verification
EPFL; CLTC; NREL; LBNL; Finelite
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Integrated lighting simulation tools. Develop high quality, validated lighting tools for daylighting design. Tools should be capable of simulating daylight, electric light, lighting controls, complex fenestration systems, and inform a whole building energy model.

Existing research: Stakeholders have indicated that there is ongoing research in this area at the California Energy Commission's (CEC) Public Interest Energy Research (PIER) program as well as at the National Renewable Energy Laboratory (NREL), with the Bonneville Power Administration), Energy Efficient Buildings Hub (EEB HUB), and the Lawrence Berkeley National Laboratory (LBNL.).

- *[Summaries of existing research pending]*

Key research questions:

1. How can we characterize complex fenestration devices at a resolution fine enough to accurately capture daylight redirection devices?
2. How can we improve existing simulation tools to improve accuracy and speed of execution?
3. How can we scale existing control simulation tools (e.g. DAYSIM, OpenStudio, SPOT) to the whole building level?
4. How can we improve the capture, delivery, and dissemination of materials and systems performance to simulation engineers?
5. How can tools be leveraged for large scale, sector-wide daylighting analyses?

Software for daylight design and sensor placement. Develop good, affordable software for designing daylighting systems, including determining optimum placement of sensors.

Existing research: Stakeholders have indicated that there is ongoing research in this area at the California Energy Commission's (CEC) Public Interest Energy Research (PIER) program .

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Improved control systems and sensors for daylighting technologies. Explore alternative ways of sensing daylight and adjust the electric lights accordingly. (Separate paths for top lighting from side lighting).

Existing research: University of California Davis California Lighting Technology Center (CLTC), National Renewable Energy Laboratory (NREL) Research Support Facility (RSF), industry research.

- For the CLTC's work in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. How do we improve reliability and cost in daylighting sensing?
2. How do we automate calibration and account for occupant needs and desires?
3. How do we integrate lighting, fenestration and HVAC controls?

Continued . . .

Cheaper, cost effective, self-calibrating daylighting controls. Making daylighting cost-effective continues to be a challenge. Easier to use, and self-calibrating controls can help to make daylighting more attractive.

Existing research: Subject matter experts indicated that research was ongoing at the Lighting Research Center (LRC), and possibly at Watt Stopper and under the aegis of the Lighting Controls Section of the Association of Electrical Equipment and Medical Imaging Manufacturers (NEMA); R&D is also ongoing at the California Lighting Technology Center (CLTC).

- Watt Stopper is researching dual-loop daylight control systems that self commission and offer continual calibration (http://cltc.ucdavis.edu/content/view/142/164/).
- The Lighting Research Center's (LRC) Capturing the Daylight Dividend program has completed R&D on daylighting systems and controls, and has also worked on a number of case studies. (http://www.lrc.rpi.edu/researchAreas/daylighting.asp).
- Information about CLTC research in this area can be found in Appendix B.

Key research questions:

1. Develop sensor/control systems for plug-and-play daylight harvesting with skylights and with windows.

Optimize daylighting with PC use. Research on how to effectively use personal computers (PCs) to monitor and control daylighting.

Existing research: Subject matter experts have indicated that Rensselaer Polytechnic Institute's Lighting Research Center (LRC) is working in this area.

- Appendix B provides an overview of research at LRC, which has upwards of sixty ongoing R&D projects at any given time. A public list of R&D progress and final reports can be found at http://www.lrc.rpi.edu/resources/newsroom/projectsheets.asp, and some additional information about LRC's research can be found in Appendix B.

Key research questions:

1. Questions not yet specified.

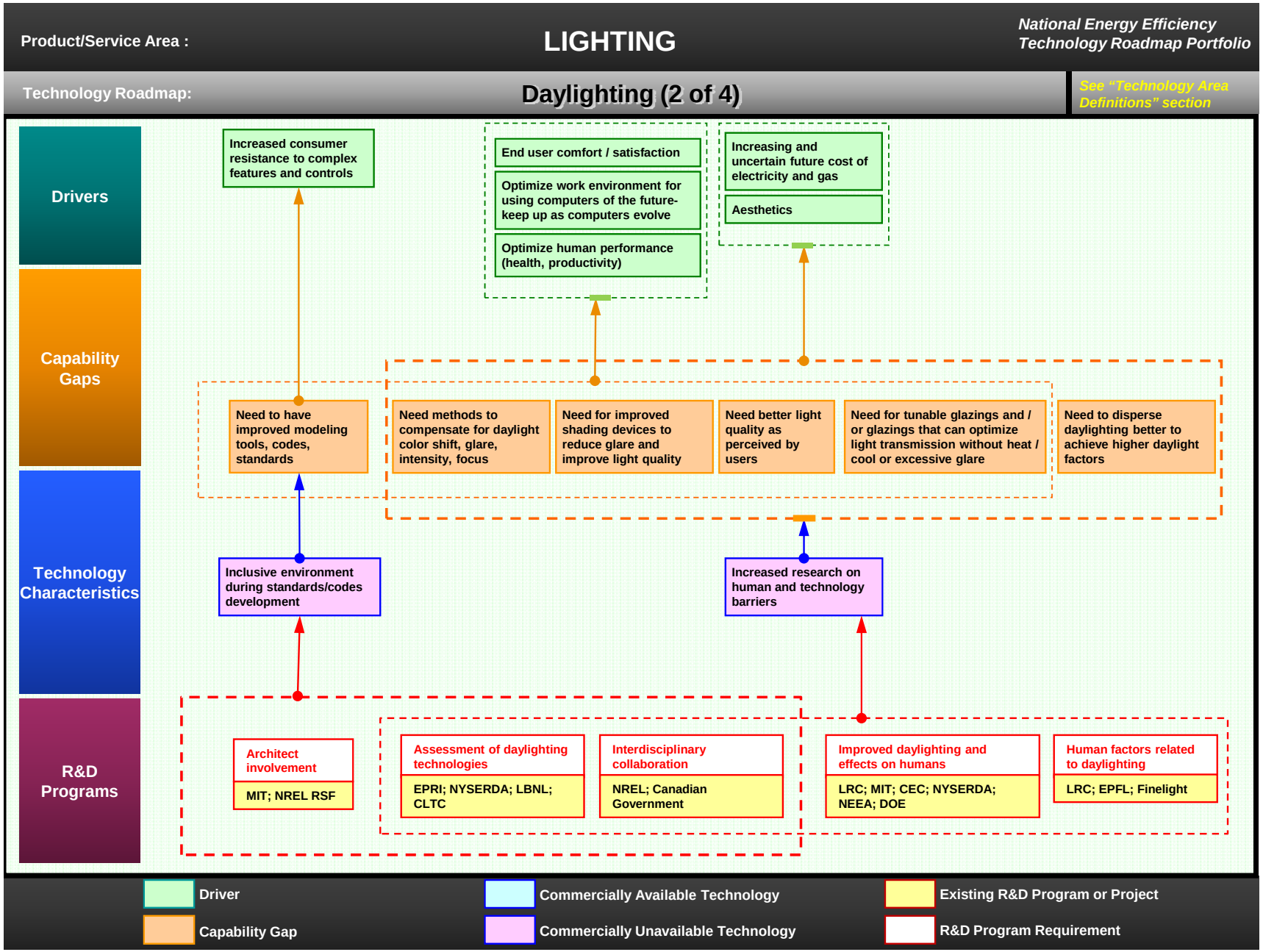
Daylighting system field testing, measurement, and verification. Need to develop and agree upon measurement protocols to fairly and consistently evaluate daylighting strategies and components.

Existing research: Research ongoing at the Swiss École Polytechnique Fédérale de Lausanne (EPFL), UC Davis California Lighting Technology Center (CLTC), National Renewable Energy Laboratory (NREL), and Finelight.

- *[Summaries of existing research pending]*

Key research questions:

1. How can we leverage HDRI to characterize daylighting systems?
2. How can we capture the occupant experience?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Daylighting (2 of 4)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Increased consumer resistance to complex features and controls
End user comfort / satisfaction
Optimize work environment for using computers of the future-keep up as computers evolve
Optimize human performance (health, productivity)
Increasing and uncertain future cost of electricity and gas
Aesthetics
Need to have improved modeling tools, codes, standards
Need methods to compensate for daylight color shift, glare, intensity, focus
Need for improved shading devices to reduce glare and improve light quality
Need better light quality as perceived by users
Need for tunable glazings and / or glazings that can optimize light transmission without heat / cool or excessive glare
Need to disperse daylighting better to achieve higher daylight factors
Inclusive environment during standards/codes development
Increased research on human and technology barriers
Architect involvement
MIT; NREL RSF
Assessment of daylighting technologies
EPRI; NYSERDA; LBNL; CLTC
Interdisciplinary collaboration
NREL; Canadian Government
Improved daylighting and effects on humans
LRC; MIT; CEC; NYSERDA; NEEA; DOE
Human factors related to daylighting
LRC; EPFL; Finelight
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Architect involvement. (Summary not yet provided.)

Existing research: Massachusetts Institute of Technology (MIT), National Renewable Energy Laboratory (NREL) Research Support Facility (RSF).

- *[Summaries of existing research pending]*

Key research questions:

1. Develop fast daylight modeling tools (with results measured in seconds, not minutes) to support decisions about daylighting during early conceptual design.

Assessment of daylighting technologies. (Summary not yet provided.)

Existing research: New York State Energy Research and Development Authority (NYSERDA), Electric Power Research Institute (EPRI), Lawrence Berkeley National Laboratory (LBNL), University of California Davis California Lighting Technology Center (CLTC).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Interdisciplinary collaboration. Successful daylighting requires that many different disciplines will be considering daylighting during design stage. (e.g. architects should size fenestration appropriately and interior designers should arrange furniture and specify interior surface reflectance appropriately).

Existing research: National Renewable Energy Laboratory (NREL), Canadian government.

- *[Summaries of existing research pending]*

Key research questions:

1. How do we bring disciplines together—architecture / daylighting, commissioning agents, interior design / electric lighting, mechanical engineering, facility managers, etc.?
2. How do we make them aware and incentivize them into using proven strategies?

Improved daylighting and effects on humans. (Summary not yet provided.)

Existing research: Rensselaer Polytechnic Institute Lighting Research Center (LRC), U.S. Department of Energy (DOE), California Energy Commission (CEC), Massachusetts Institute of Technology (MIT), New York State Energy Research and Development Authority (NYSERDA), Northwest Energy Efficiency Alliance (NEEA).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Continued . . .

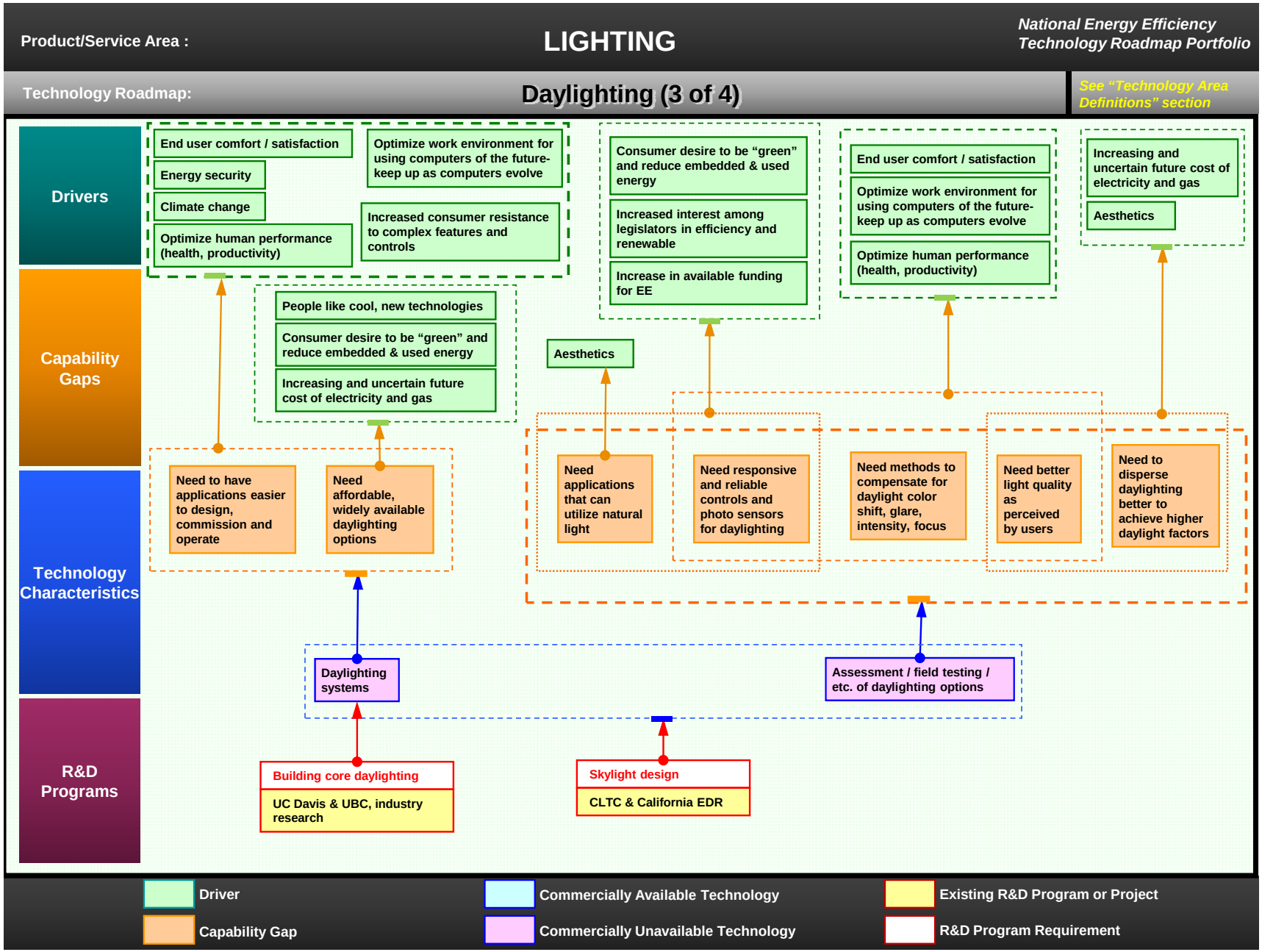
Human factors related to daylighting. Human acceptance, preference, and needs are critical for successful daylighting. Need to understand them and design accordingly.

Existing research: Rensselaer Polytechnic Institute Lighting Research Center (LRC), École Polytechnique Fédérale de Lausanne (EPFL).

- Appendix B provides an overview of research at LRC, which has upwards of sixty ongoing R&D projects at any given time. A public list of R&D progress and final reports can be found at http://www.lrc.rpi.edu/resources/newsroom/projectsheets.asp, and some additional information about LRC's research can be found in Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. What are the physical and psychological effects on humans?
2. How should we manage daylight for computer use?
3. How should we ensure occupant acceptance of lighting controls and fenestration controls?


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Daylighting (3 of 4)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
End user comfort / satisfaction
Energy security
Climate change
Optimize human performance (health, productivity)
Optimize work environment for using computers of the future-keep up as computers evolve
Increased consumer resistance to complex features and controls
Consumer desire to be "green" and reduce embedded & used energy
Increased interest among legislators in efficiency and renewable
Increase in available funding for EE
End user comfort / satisfaction
Optimize work environment for using computers of the future-keep up as computers evolve
Optimize human performance (health, productivity)
Increasing and uncertain future cost of electricity and gas
Aesthetics
People like cool, new technologies
Consumer desire to be "green" and reduce embedded & used energy
Increasing and uncertain future cost of electricity and gas
Aesthetics
Need to have applications easier to design, commission and operate
Need affordable, widely available daylighting options
Need applications that can utilize natural light
Need responsive and reliable controls and photo sensors for daylighting
Need methods to compensate for daylight color shift, glare, intensity, focus
Need better light quality as perceived by users
Need to disperse daylighting better to achieve higher daylight factors
Daylighting systems
Assessment / field testing / etc. of daylighting options
Building core daylighting
UC Davis & UBC, industry research
Skylight design
CLTC & California EDR
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Building core daylighting. Daylighting has traditionally concentrated on perimeter zones (near windows). Bringing daylighting into the core of buildings i.e. areas away from windows and skylights.

Existing research: There is an ongoing research partnership between the University of British Columbia (UBC) and the California Lighting Technology Center (CLTC) to provide daylighting in core zones, but more research is needed to find more affordable and effective ways of doing this. Firms in the industry are conducting research also, as is the Lawrence Berkeley National Laboratory (LBNL).

- The CLTC is currently working on an R&D project to evaluate the application of UBC's Core Sunlighting System to the climate and topography of California's Central Valley. See Appendix B for more information on this effort.
- For LBNL's work in this area, see Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. How do we collect?
2. How do we transport?
3. How do we deliver?
4. How do we integrate with electric lighting?

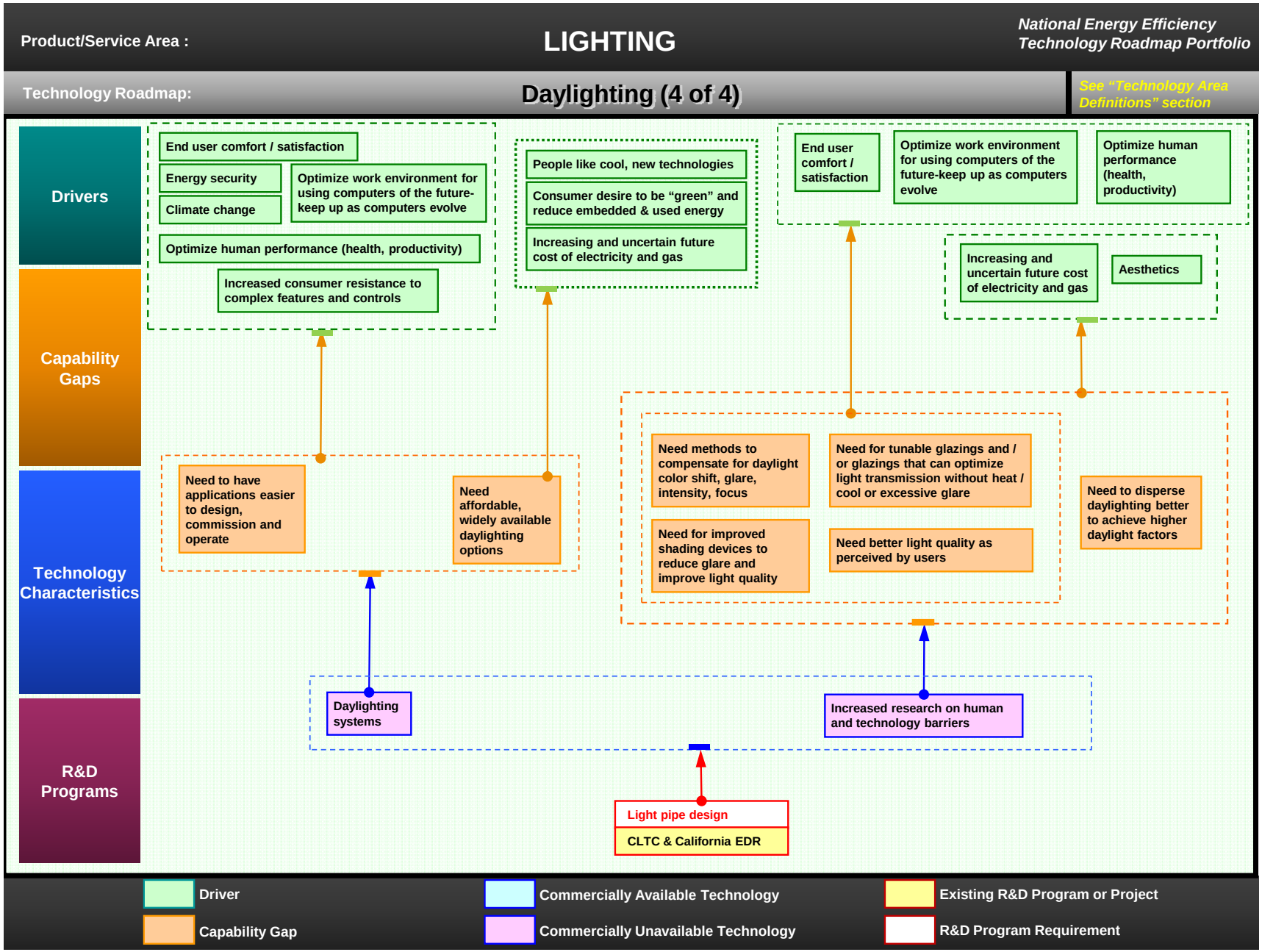
Skylight design. Making daylighting cost-effective continues to be a challenge. Effective, affordable, leak-resistant skylight design could help make daylighting easier and more affordable to adopt.

Existing research: The California Lighting Technology Center (CLTC) is engaged in ongoing R&D in this area, and California Energy Design Resources (EDR) website provides a list of skylight and daylighting resources.

- Information about CLTC's ongoing research into sunlighting and solatube skylight systems can be found in Appendix B.
- California's utility ratepayers fund the state's EDR program; Southern California Edison administers the program under the auspices of the California Public Utilities Commission (CPUC). The EDR website serves as a portal for architects, engineers, lighting designers, and developers to access energy design tools and resources that will foster energy-efficient commercial and industrial building design. EDR resources include daylighting and sky light design (http://www.energydesignresources.com/technology/daylighting-design.aspx, http://www.energydesignresources.com/resources/publications/design-briefs/design-brief-skylights-with-suspended-ceilings.aspx).

Key research questions:

1. Questions not yet specified.


Product/Service Area :
LIGHTING
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Daylighting (4 of 4)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
End user comfort / satisfaction
Energy security
Climate change
Optimize work environment for using computers of the future-keep up as computers evolve
Optimize human performance (health, productivity)
Increased consumer resistance to complex features and controls
People like cool, new technologies
Consumer desire to be "green" and reduce embedded & used energy
Increasing and uncertain future cost of electricity and gas
End user comfort / satisfaction
Optimize work environment for using computers of the future-keep up as computers evolve
Optimize human performance (health, productivity)
Increasing and uncertain future cost of electricity and gas
Aesthetics
Need to have applications easier to design, commission and operate
Need affordable, widely available daylighting options
Need methods to compensate for daylight color shift, glare, intensity, focus
Need for tunable glazings and / or glazings that can optimize light transmission without heat / cool or excessive glare
Need for improved shading devices to reduce glare and improve light quality
Need better light quality as perceived by users
Need to disperse daylighting better to achieve higher daylight factors
Daylighting systems
Increased research on human and technology barriers
Light pipe design
CLTC & California EDR
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Light pipe design. (Summary not yet provided.)

Existing research: University of California Davis and California Energy Design Resources (EDR).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Electronics Roadmaps

This section contains the following roadmaps:

- Direct Current (DC) Power
- Use and Virtualization
- Component-Level Efficiency
- Complete Electronic System
- Power Management Control and Communication

Other relevant sources:

The list below is intended to be broadly representative rather than exhaustive and will be updated as new information becomes available.

Staff at the Lawrence Berkeley National Laboratory held a direct current (DC) power workshop on Feb. 7, 2013, to define technology, policy, market adoption, and other barriers to wide-scale adoption of integrated DC power systems that include renewable generation, grid supply, energy storage, distribution, communication, demand control, and end uses. Workshop findings are pending as of March 2013.

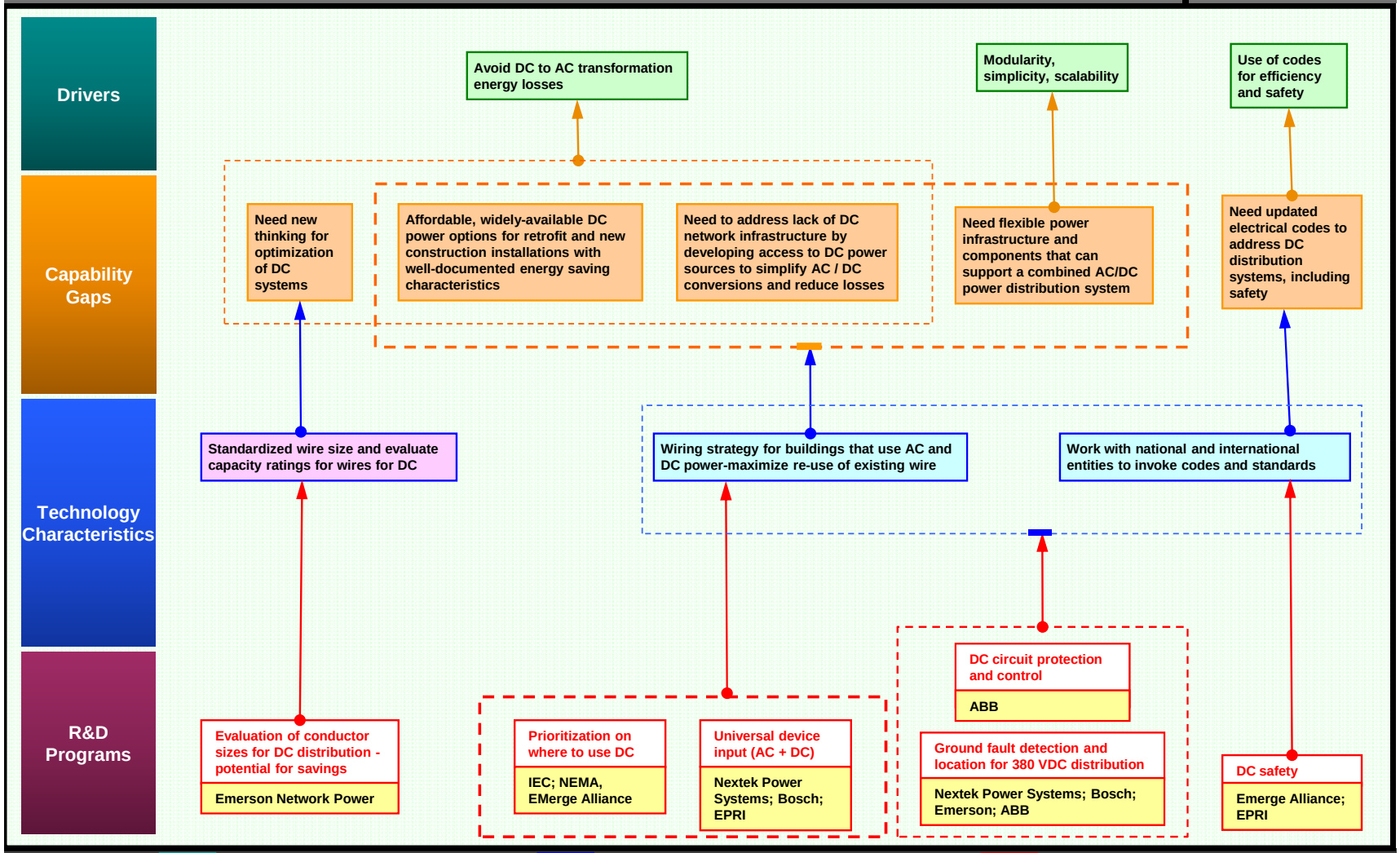
Lawrence Berkeley National Laboratory, *High-Performance Data Centers: A Research Roadmap*, July 2003, http://hightech.lbl.gov/ documents/ datacenters_roadmap_final.pdf.

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Direct Current (DC) Power (1 of 4)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Evaluation of conductor sizes for DC distribution - potential for savings. Optimize wire sizes for global applications. Conductor sizes coordinated globally-minimum sizes, insulation levels for DC applications only. Different wire sizes and insulation levels from requirements globally.

Existing research: Emerson Network Power.

- *[Summaries of existing research pending]*

Key research questions:

1. Can DC cable size decrease (compared to AC) due to lack of harmonics, skin effect, proximity effect and smaller voltage drop (compared to the National Electrical Code (NEC))?
2. Is it feasible to propose a global wire size chart coordinated with breaker sizes?
3. Is it feasible to develop (specifically for DC) temperature de-rating tables in "A" capacity rather than apply de-rating factors?
4. Is it feasible to optimize insulation levels to optimize current carrying capacity?
5. Can we define derating for bundling?
6. Can we use existing building wiring for DC power distribution?

Ground fault detection and location for 380 VDC distribution. Enhanced personal safety. Integrated DC system including DC microgrids. Rapid detection, location and correction of potential ground faults and leakage current caused by insulation breakdown or aging.

Existing research: Emerson Network Power, ABB, Nextek Power Systems, Bosch.

- *[Summaries of existing research pending]*

Key research questions:

1. What are the best methods to detect ground faults in the DC distribution system including the end use equipment?
2. What sensors and components are needed for ground faults and where should they be located?
3. How can these sensors, components and alarms ne scaled to different size installations?
4. What is the cost of implementing these ground fault detection, location and correction systems?
5. What additional training is needed to implement these systems to assure proper operation?

Continued . . .

DC safety. Direct current (DC) acts very differently from alternating current (AC), so we need a whole new set of safety standards, education, and training so that people understand and implement DC safely.

Existing research: Emerge Alliance and the Electric Power Research Institute (EPRI) are working to develop DC power standards for commercial buildings that address safety concerns..

- For EPRI's and Emerge Alliance's work in this area, see Appendix B.

Key research questions:

1. What codes and standards needed to be changed or developed for DC power?
2. What training facilities are available to train people on DC power?
3. What training requirements are needed for DC compared to AC systems?

DC circuit protection and control. Explore existing, new and potential new technologies for DC circuit protection and control.

Existing research: ABB.

- *[Summaries of existing research pending]*

Key research questions:

1. What short circuit testing can be done for DC power distribution?
2. What circuit breakers and fuses are available for DC circuit protection?
3. How can rectifiers and other DC power source subsystems and controls be used to limit arc flash and enhance load flow control?
4. How can power electronics (i.e., integrated circuits (ICs)) be used to improve circuit protection and control in DC power systems?
5. What new technologies are available to enhance circuit protection and control for DC power systems?

Prioritization on where to use DC. DC systems will need to transition from existing AC systems. The goal is to identify how to make the transitioning by identifying the highest profile opportunities for DC based on efficiency gains and cost of implementation.

Existing research: IEC Electronics Corporation, National Electrical Manufacturers Association (NEMA), EMerge Alliance.

- *[Summaries of existing research pending]*

Key research questions:

1. Where are the key locations in the buildings where efficiency can be achieved?
2. What is the amount of efficiency that can be gained?
3. How much DC supply is available and how should it be best used in the buildings?
4. Based on the DC supply available which equipment should be converted to DC first?

Continued . . .

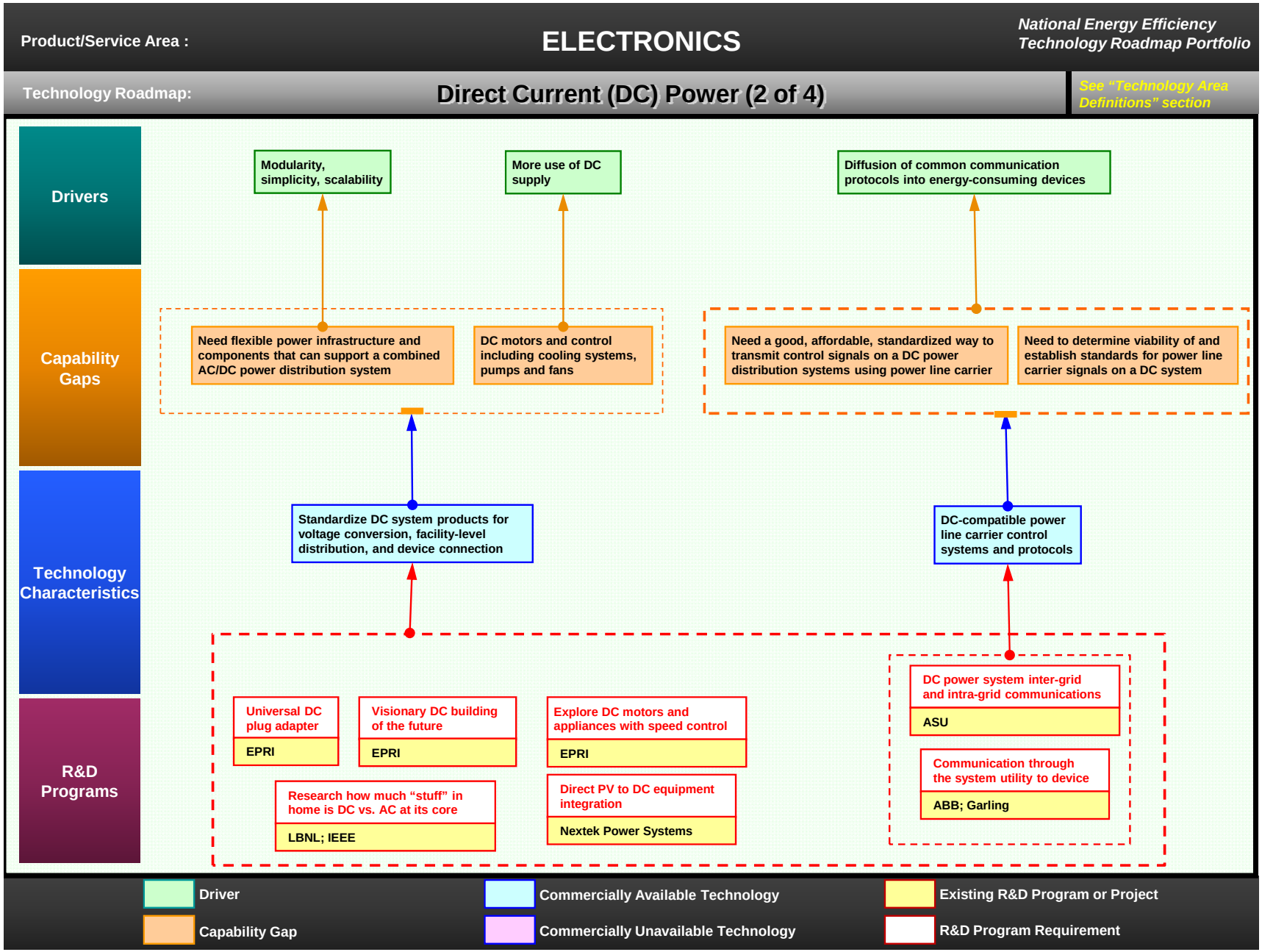
Universal device input (AC + DC). Device circuit technology for common electrical devices that can accept either connection to an AC or DC power distribution system.

Existing research: The Electric Power Research Institute (EPRI), Nextek Power Systems, and Bosch are conducting research in this area.

- For EPRI's research in this area, see Appendix B for more information
- *[Summaries of other existing research pending]*

Key research questions:

1. Circuit design for AC/DC inputs.
2. Low cost design with minimal premium cost.
3. Safety issues.
4. Code issues.
5. Cords and connector designs.


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Direct Current (DC) Power (2 of 4)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Modularity, simplicity, scalability
More use of DC supply
Diffusion of common communication protocols into energy-consuming devices
Need flexible power infrastructure and components that can support a combined AC/DC power distribution system
DC motors and control including cooling systems, pumps and fans
Need a good, affordable, standardized way to transmit control signals on a DC power distribution systems using power line carrier
Need to determine viability of and establish standards for power line carrier signals on a DC system
Standardize DC system products for voltage conversion, facility-level distribution, and device connection
DC-compatible power line carrier control systems and protocols
Universal DC plug adapter
EPRI
Visionary DC building of the future
EPRI
Explore DC motors and appliances with speed control
EPRI
Research how much "stuff" in home is DC vs. AC at its core
LBNL; IEEE
Direct PV to DC equipment integration
Nextek Power Systems
DC power system inter-grid and intra-grid communications
ASU
Communication through the system utility to device
ABB; Garling
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Explore DC motors and appliances with speed control. Since variable speed is easy to do with DC motors, having DC in the building may allow the possibility of using many more DC motors for variable-speed applications. The economic advantages are greatest when there is a large number of DC motors or DC electronic loads that can all operate, or be easily adapted to operate, on the same DC voltage.

Existing research: Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. What are the efficiency gains with brushless DC motors?
2. What are the control benefits of DC motors, i.e., higher speeds, faster response, torque characteristics?
3. What are the benefits of DC motors for size, maintenance and heat removal?
4. What are the benefits of brushless DC motors for reduced radio frequency interference (RFI)?
5. What components can be removed when transitioning from AC variable frequency drives (VFDs) to brushless DC motors?

Universal DC plug adapter. One of the issues with converting to DC is that plug and sockets are totally non-standard. The development of a universal plug for DC will greatly aid adoption.

Existing research: The Electric Power Research Institute (EPRI) is conducting research in this area, see Appendix B for more information..

Key research questions:

1. How do different DC plugs and sockets currently available handle and control arc-flash?
2. Can the existing Institute of Electrical and Electronics Engineers International Electrotechnical Commission (IEC) 309 pin and sleeve connectors cover "all" of the high wattage DC product needs?
3. What is the best solution(s) for the lower wattage DC products?

Research how much "stuff" in home is DC vs. AC at its core. Typical home to justify having a DC supply in homes. It is unlikely that the load of DC in a home is enough to justify supplying DC.

Existing research: Lawrence Berkeley National Laboratory (LBNL), Institute of Electrical and Electronics Engineers (IEEE).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Continued . . .

Direct PV to DC equipment integration. Solar photovoltaic (PV) systems may supply DC directly rather than converting to AC and back again. This will be most effective if the voltage of the PV system is matched with the most common voltage needed by the DC equipment. Research is needed to determine how to do this most effectively.

Existing research: Nextek Power Systems.

- *[Summaries of existing research pending]*

Key research questions:

1. Which DC powered devices offer the best opportunity to be powered directly in residential and commercial applications?
2. What types of buildings are best suited? What system characteristics define the best opportunities in new buildings?
3. Where is PV added to existing buildings/facilities? What additional equipment and systems (safety, control, and integration) are needed?

Visionary DC building of the future. Taking a new approach to create an all DC environment that includes electrical configuration, storage, end use devices, distribution, safety devices.

Existing research: Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. What metered resource savings can be achieved?
2. What are the technical challenges, lessons learned in putting this together?
3. What are the areas of this optimal solution that cannot be addressed by code?
4. What are the energy savings and the distribution of these savings?

DC power system inter-grid and intra-grid communications. The creation of arbitrary networks of grids of varying scales with dynamic plug and play interoperability.

Existing research: Arizona State University (ASU)

- *[Summaries of existing research pending]*

Key research questions:

1. Can we create a network of grids that are interconnected and exchanging power based on price signals?
2. Can a grid be built that communicates with individual devices and includes price signals?
3. Can we define specific gateways between grids for both electrical and communication connections for grid to grid data interchange?

Communication through the system utility to device. With DC systems information can more reliably be sent via carrier signals on the same infrastructure (wires).

Existing research: ABB and Garling are working on breakers.

- *[Summaries of existing research pending]*

Key research questions:

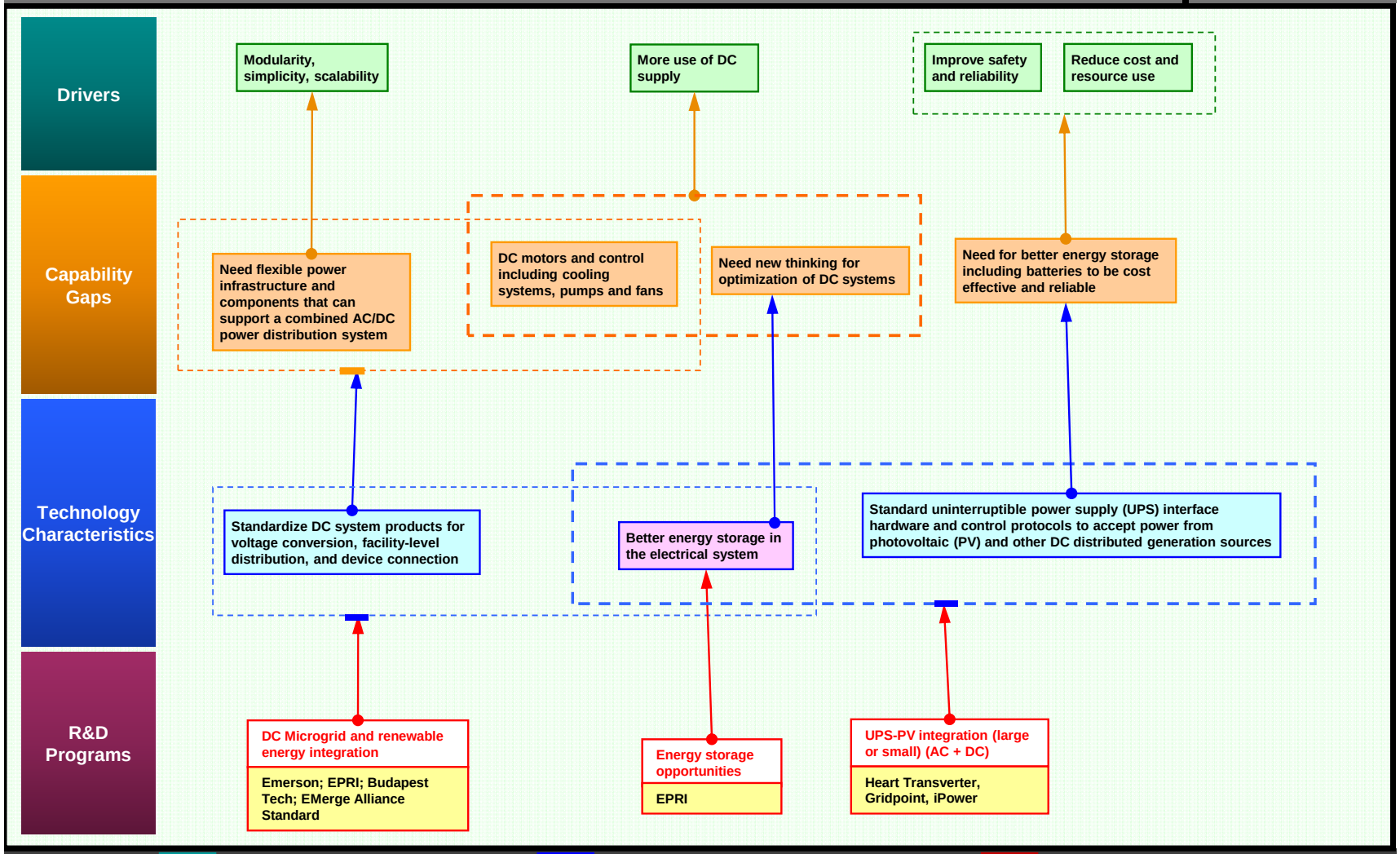
1. Can carrier signals be effectively used to communicate peer to peer between appliances as well as connecting communication to utility signals?
2. How can carrier signals transfer across DC voltage conversion devices?
3. What communications protocol is the best to use on DC wiring?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Direct Current (DC) Power (3 of 4)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Energy storage opportunities. New options exist for the integration of energy storage into a DC power system since the entire system can act as a DC link.

Existing research: Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. How and where can batteries and/or other energy storage systems be connected within a DC system?
2. How can electric vehicles (EVs) be connected to DC systems for charge and discharge requirements?
3. Can batteries and/or other battery storage systems be located and connected at various locations in a DC power system in order to meet differing component level reliability requirements?

DC Micro grid and renewable energy integration. DC power enables the opportunity to create DC microgrids which integrate, multiple power sources and can feed multiple loads while in both island mode and grid connected mode.

Existing research: Emerson, Electric Power Research Institute (EPRI), Budapest Tech [Budapest University of Technology and Economics?], EMerge Alliance Standard.

- *[Summaries of existing research pending]*

Key research questions:

1. How can a DC microgrid be designed, built, and operated?
2. Can fuel *[not discernible]* be used to power a DC power system?

UPS -PV integration (large or small). A common entry point for DC power (such as DV system or fuel cells) is to integrate with uninterruptible power systems (UPS) that use batteries as the storage element. These systems can be used in a large variety of backup systems from small back-up to datacenters to E-power for buildings. Solar photovoltaic (PV) systems, too, may supply DC directly rather than converting to AC and back again. Research is needed to determine how most effectively to do this.

Existing research: Heart Transverter, Gridpoint , and iPower are working in this area.

- Heart Transverter developed a 2 kW power management device and control hardware for integrating PV, electric vehicles, battery banks, and some other combinations of AC or DC within its power range. See Appendix B for more information.
- Gridpoint seems to have designed a product that is specifically meant to integrate with PV. See Appendix B for more information.
- iPower's offering promises to tailor its UPS to specific distributed generation systems for an added cost. See Appendix B for more information.
-

Key research questions:

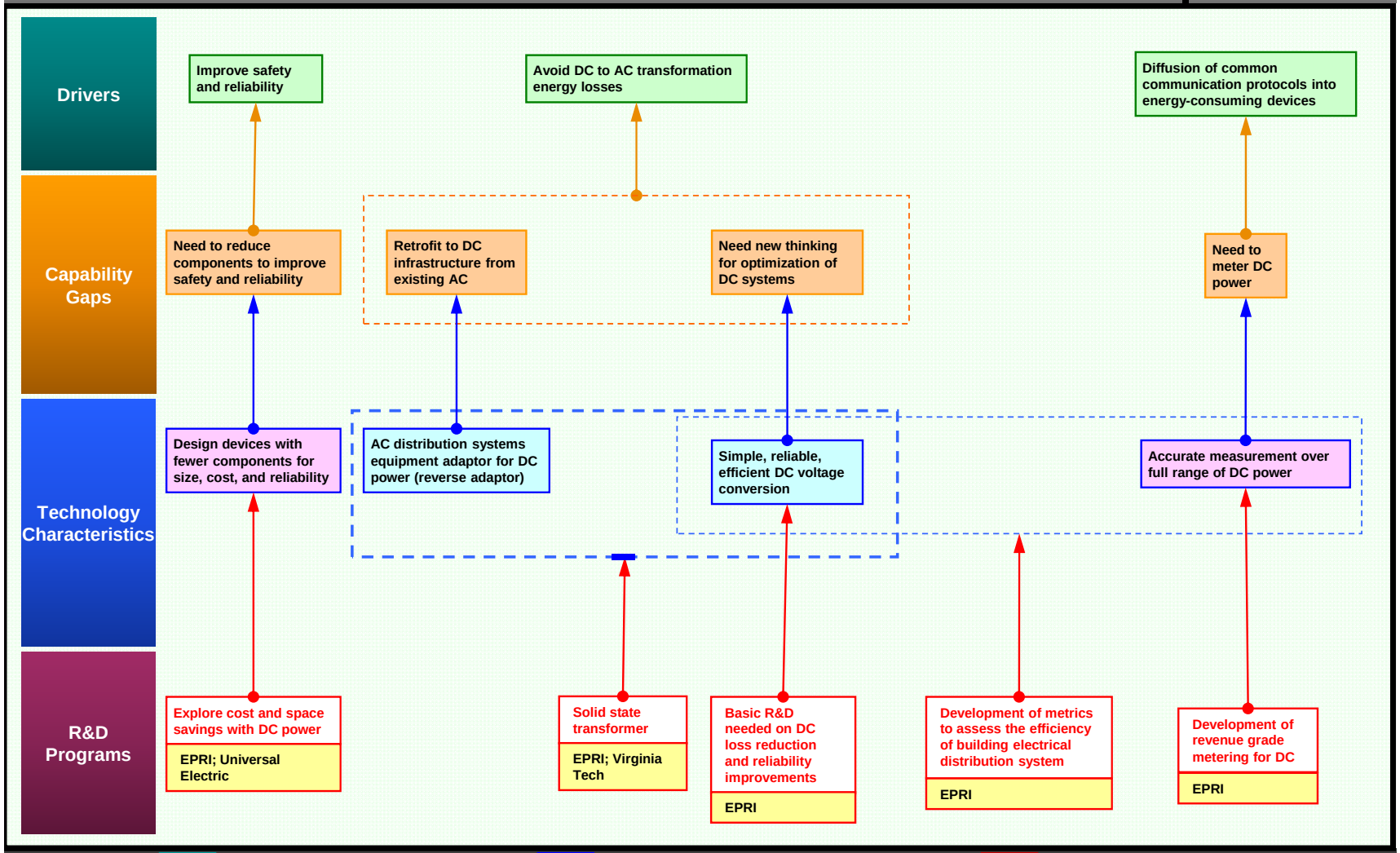
1. Do different batteries (deep cycle) need to be used compared to existing UPS systems?
2. How much overall system efficiency can be achieved?
3. Can UPS system be more designed like grid independent PV battery systems? What are the differences and how can the experiences of grid independent systems be copied to UPS systems?
4. What are the differences in UPS systems from data centers to E-power systems for commercial and residential buildings?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Direct Current (DC) Power (4 of 4)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Basic R&D needed on DC loss reduction and reliability improvements. The concept of using DC power supply in a data center makes intuitive sense, but it is not well tested, especially in comparison to other approaches such as using higher AC supply voltage (230V.). Basic proof-of-concept and maybe some small trials are needed before expanding further.

Existing research: The Electric Power Research Institute (EPRI) is assessing efficiency and loss-reduction potential for distribution technologies in general, including for DC power. See Appendix B for more information.

Key research questions:

1. Can we set up a permanent national DC power test lab where public, industry and government can see a proof of concept system in operation?

Explore cost and space savings with DC power. Comparing similar power distribution system designs for AC + DC systems. What are the cost and space savings when going from AC to DC.

Existing research: Electric Power Research Institute (EPRI), Universal Electric.

- *[Summaries of existing research pending]*

Key research questions:

1. How does DC power compare with a similar AC systems regarding total cost of ownership (TCO)?
2. How does DC power compare with similar AC systems regarding equipment space requirements?

Development of revenue grade metering for DC. (Summary not yet provided.)

Existing research: Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. Can we measure accurately over the entire range of end use devices?
2. What is needed to make these meters compatible with current generation of AC meters?

Continued . . .

Development of metrics to assess the efficiency of building electrical distribution system. Create a distribution efficiency metric. 100% efficient systems should have no losses.

Existing research: Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. What is the efficiency of the distribution system in different building types?
2. Where are the losses?
3. What is the efficiency of a DC based buildings?
4. What are the key metrics of success and the measurement protocol to determine?
5. Are there analytical means to define the metric?

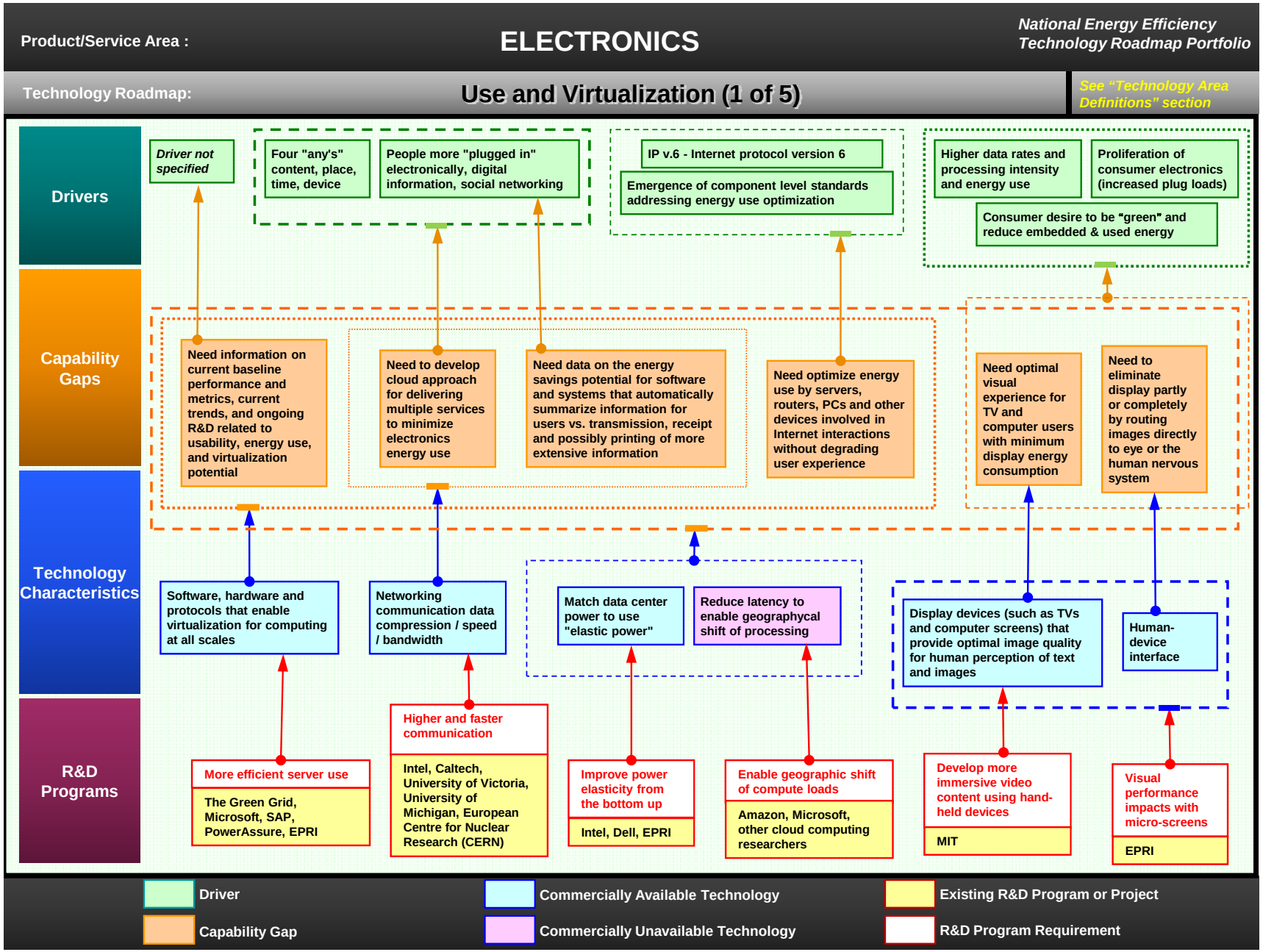
Solid state transformer. It is desired to incorporate voltage transformation with rectification of building power. This will reduce conversion losses and number of power devices.

Existing research: Electric Power Research Institute (EPRI), Virginia Polytechnic Institute and State University.

- *[Summaries of existing research pending]*

Key research questions:

1. How can you efficiently and reliably convert utility distribution power (at 12 kV) to 380 VDC or any other desired voltage?


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Use and Virtualization (1 of 5)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Driver not specified
Four "any's" content, place, time, device
People more "plugged in" electronically, digital information, social networking
IP v.6 - Internet protocol version 6
Emergence of component level standards addressing energy use optimization
Higher data rates and processing intensity and energy use
Proliferation of consumer electronics (increased plug loads)
Consumer desire to be "green" and reduce embedded & used energy
Need information on current baseline performance and metrics, current trends, and ongoing R&D related to usability, energy use, and virtualization potential
Need to develop cloud approach for delivering multiple services to minimize electronics energy use
Need data on the energy savings potential for software and systems that automatically summarize information for users vs. transmission, receipt and possibly printing of more extensive information
Need optimize energy use by servers, routers, PCs and other devices involved in Internet interactions without degrading user experience
Need optimal visual experience for TV and computer users with minimum display energy consumption
Need to eliminate display partly or completely by routing images directly to eye or the human nervous system
Software, hardware and protocols that enable virtualization for computing at all scales
Networking communication data compression / speed / bandwidth
Match data center power to use "elastic power"
Reduce latency to enable geographycal shift of processing
Display devices (such as TVs and computer screens) that provide optimal image quality for human perception of text and images
Human-device interface
More efficient server use
The Green Grid, Microsoft, SAP, PowerAssure, EPRI
Higher and faster communication
Intel, Caltech, University of Victoria, University of Michigan, European Centre for Nuclear Research (CERN)
Improve power elasticity from the bottom up
Intel, Dell, EPRI
Enable geographic shift of compute loads
Amazon, Microsoft, other cloud computing researchers
Develop more immersive video content using hand-held devices
MIT
Visual performance impacts with micro-screens
EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

More efficient server use. Quantify generic capacity and utilization metrics that address "Z sigma" (i.e., 60-70%) of data center metric needs. Focus on enterprise/small medium business.

Existing research: The Green Grid, Microsoft, SAP, PowerAssure, Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. How should compute requirement (capacity) be quantified?
2. Develop a generic "yardstick" ala "MIPS" that can be used to better plan hardware (HW) capacity and measure utilization.
3. As providers manage hardware (HW) pools compared to computer demand what metrics unit do they use to maximize profits?

Improve power elasticity from the bottom up . Components are good at scaling energy use with load but that capability is lost in populations of machines and applications. Explore ways to extend elastic power use from component to data centers.

Existing research: Intel, Dell, Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. Why do applications not show the same power elasticity as chips, i.e., reducing energy consumption with reduce load?
2. Why do data centers not show the same elasticity as machines, i.e., whole building power elasticity compared to SPEC-power capabilities?

Higher and faster communication. Investigate the family of technology options that are effective at transferring larger amounts of data at higher rates. This includes examining compression techniques, communication protocols, expansion of bandwidth and the use of networks. The work should addressed both distributed and control processing.

Existing research: Intel, Caltech, University of Victoria (British Columbia), University of Michigan, European Centre for Nuclear Research (CERN).

- *[Summaries of existing research pending]*

Key research questions:

1. Which data compression techniques are available?
2. What are the best communication protocols?
3. What are practical networking/communication speeds?
4. How can communication bandwidth be expanded as well as utilization of bandwidths?
5. How much processing can be applied at distributed devices versus being connected server/host?

Continued . . .

Enable geographic shift of computer loads. The vast majority of applications are interactive or human driven, requiring sub-second response times. Latency between several consumers drives geographic proximity today. Break the link between geography and application performance.

Existing research: Amazon, Microsoft, other cloud computing researchers.

- *[Summaries of existing research pending]*

Key research questions:

1. Programming techniques that enable high latency between server and network edge; be able to see results on smart phones in Europe with acceptable performance from servers in the U.S. This would enable load shifting without regard to geography.
2. What percentage of apps is interactive/human driven? What percentage could be geography independent with proper programming methods?

Visual performance impacts with micro-screens. Using smaller computer screens saves energy, but for some applications performance may be reduced such that this is not feasible. Research user feedback. Finding one user preference when performing different tasks. Reduce unnecessary devices if we can optimize user experience.

Existing research: Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. What is optimal micro-screen size for different devices?
2. Is there a need for a bigger than 65" TV? (4K TV)
3. What are the pros and cons between liquid crystal display (LCD) Vs Plasma Vs. light-emitting diode (LED)?

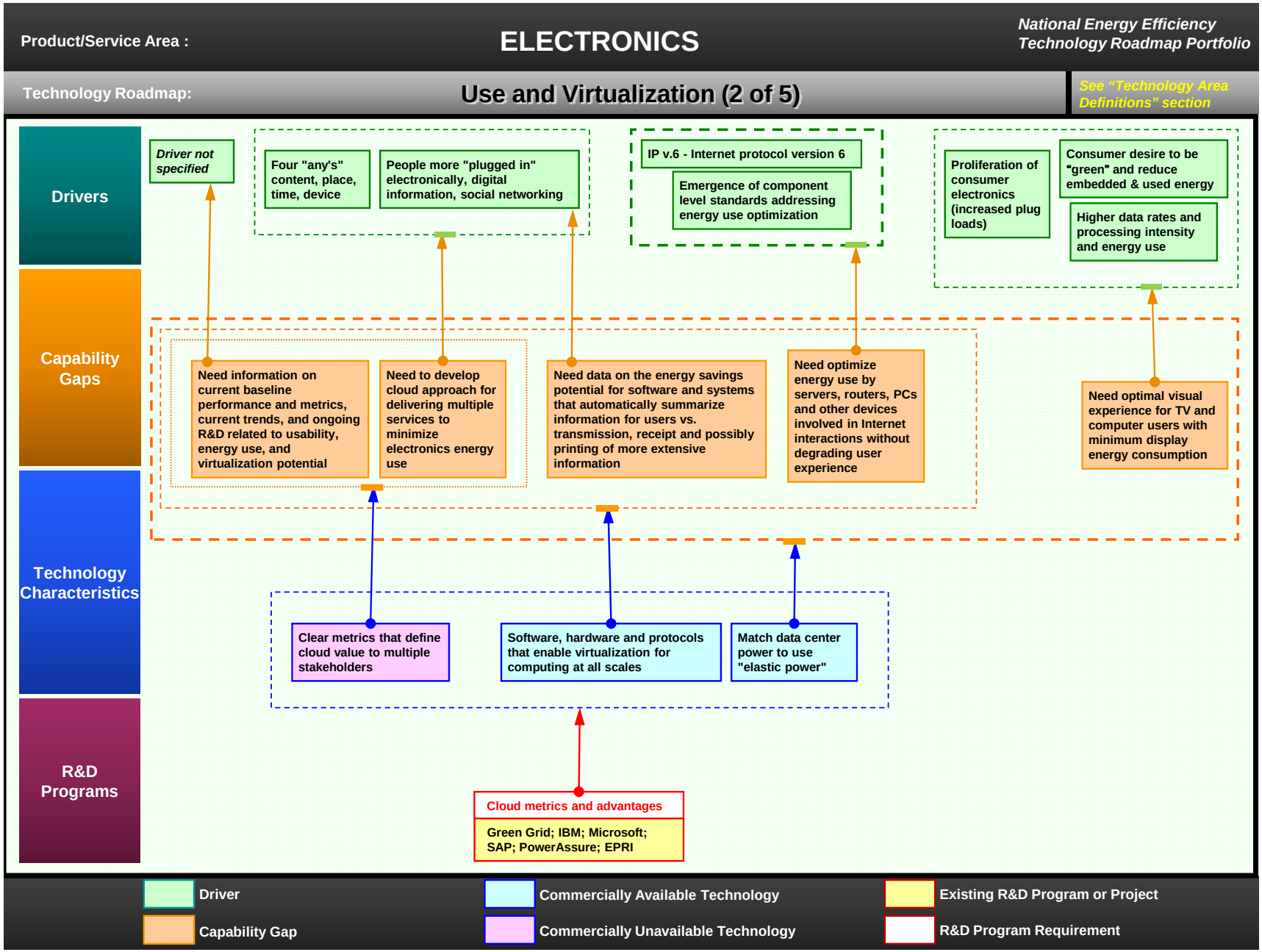
Develop more immersive video content using hand-held devices. Virtual reality (VR) goggles can replace displays using much more energy, but research is needed on user comfort with VR goggles. Also examine the potential savings, comfort, and usability of miniaturized displays embedded in traditional eyeglass frames.

Existing research: Massachusetts Institute of Technology (MIT) Media Lab.

- The MIT Media Lab is currently researching VR viewing technology; see Appendix B for more information.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Use and Virtualization (2 of 5)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Driver not specified
Four "any's" content, place, time, device
People more "plugged in" electronically, digital information, social networking
IP v.6 - Internet protocol version 6
Emergence of component level standards addressing energy use optimization
Proliferation of consumer electronics (increased plug loads)
Consumer desire to be "green" and reduce embedded & used energy
Higher data rates and processing intensity and energy use
Need information on current baseline performance and metrics, current trends, and ongoing R&D related to usability, energy use, and virtualization potential
Need to develop cloud approach for delivering multiple services to minimize electronics energy use
Need data on the energy savings potential for software and systems that automatically summarize information for users vs. transmission, receipt and possibly printing of more extensive information
Need optimize energy use by servers, routers, PCs and other devices involved in Internet interactions without degrading user experience
Need optimal visual experience for TV and computer users with minimum display energy consumption
Clear metrics that define cloud value to multiple stakeholders
Software, hardware and protocols that enable virtualization for computing at all scales
Match data center power to use "elastic power"
Cloud metrics and advantages
Green Grid; IBM; Microsoft; SAP; PowerAssure; EPRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

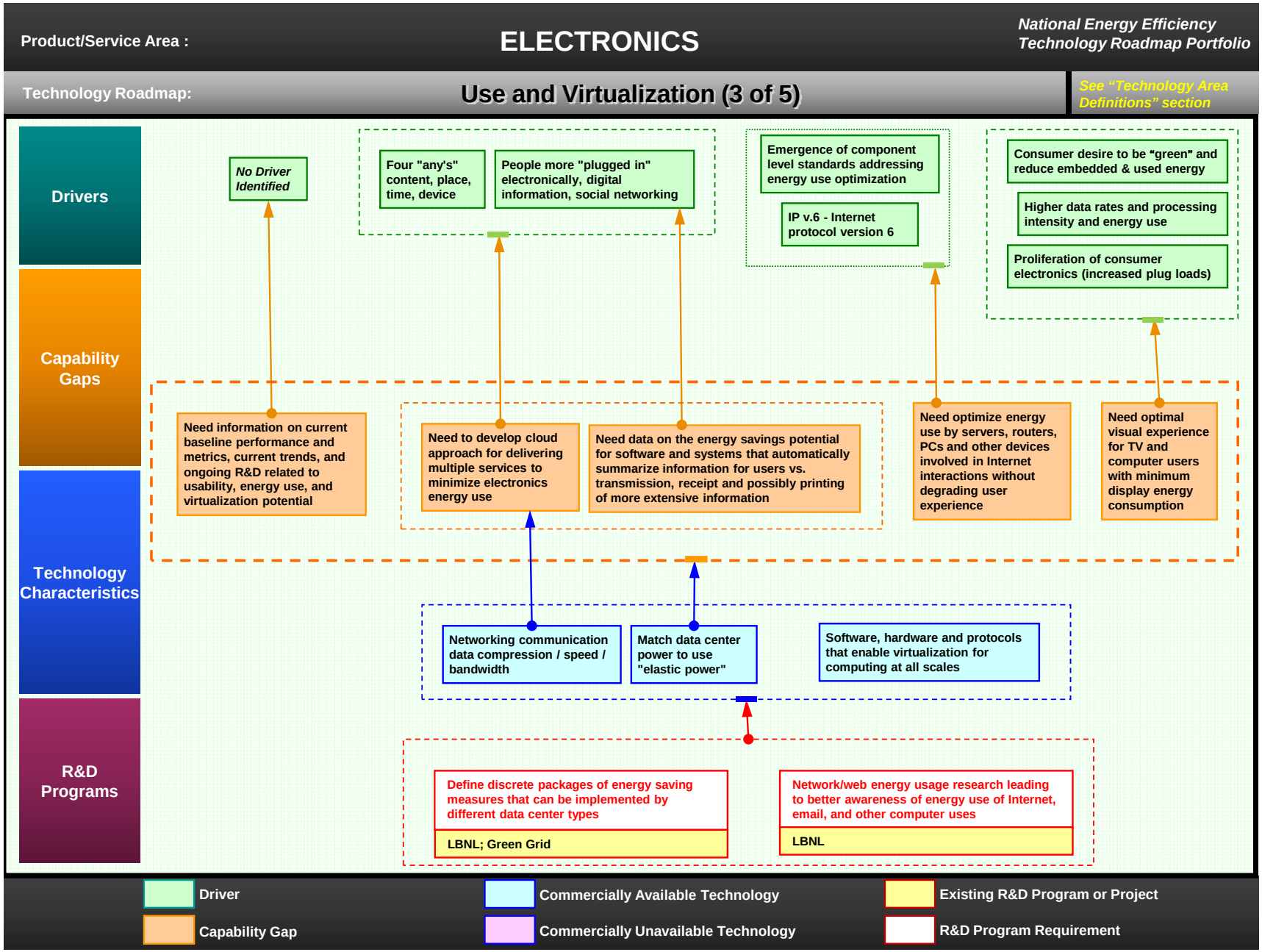
Cloud metrics and advantages. Develop metrics that quantify the intuitive understanding that cloud computing is more efficient than disaggregated computing models.

Existing research: Green Grid, IBM, Microsoft, SAP, PowerAssure.

- Dr. Zeydy Ortiz, Senior Performance Engineer in the Systems & Technology Group at IBM (http://expertintegratedsystemsblog.com/index.php/author/zeydy-ortiz/).
- Subject matter experts in September 2012 referred to the work of Timo Szeltzer at SAP.
- Clemens Pfeiffer, Chief Technology Officer at PowerAssure (http://www.powerassure.com/).

Key research questions:

1. What are the barriers to adoption of aggregated (i.e., cloud or centralized) computing?
2. Define metrics and demonstrate the utility (usefulness) of many dimensions of cloud, e.g., cost reliability.
3. Quantify the benefits of moving compute capacity to centralized resources, e.g., dumber. Cheaper. More efficient edge devices (smart phones) and more efficient centralized compute utilities (cloud). How much system-wide savings (cost, energy, carbon, etc)?
4. What else could solve this besides cloud?


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Use and Virtualization (3 of 5)
See "Technology Area Definitions" section
Drivers
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Technology Characteristics
R&D Programs
No Driver Identified
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Need optimal visual experience for TV and computer users with minimum display energy consumption
Networking communication data compression / speed / bandwidth
Match data center power to use "elastic power"
Software, hardware and protocols that enable virtualization for computing at all scales
Define discrete packages of energy saving measures that can be implemented by different data center types
LBNL; Green Grid
Network/web energy usage research leading to better awareness of energy use of Internet, email, and other computer uses
LBNL
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Define discrete packages of energy saving measures that can be implemented by different data center types. Small data centers are different needs and issues than large data centers. How can lesson learned from large data centers be applied to small data centers?.

Existing research: Lawrence Berkeley National Laboratory (LBNL), Green Grid.

- *[Summaries of existing research pending]*

Key research questions:

1. Are there simple measures that reduce energy use of small data centers?
2. What are the achievable cost effective levels of energy savings?
3. What are barriers that increase savings cost and/or reduce the magnitude of achievable savings?

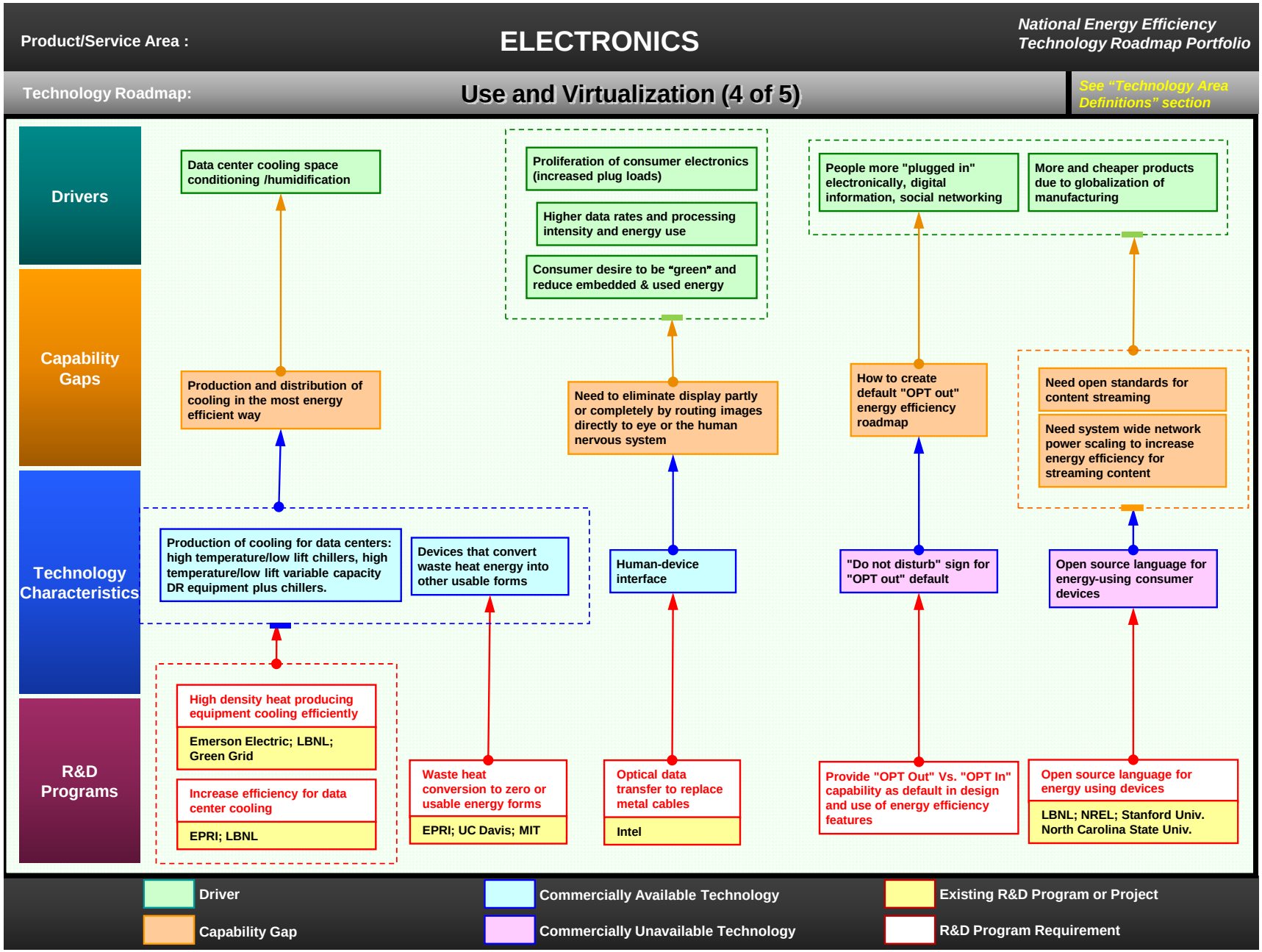
Network/web energy usage research leading to better awareness of energy use of Internet, email, and other computer uses. Many users consider it environmentally benign to transfer information electronically rather than with paper, but there is substantial energy use for this; research this and raise user awareness. As a subtopic, perform a literature search to identify the manufacturers, national labs, and other organizations involved with R&D on the broader use of optical data transfer, which is more energy efficient than metal cables.

Existing research: Lawrence Berkeley National Laboratory (LBNL).

- For more information on LBNL research in this area, see Appendix B

Key research questions:

4. Are there simple measures that reduce energy use of small data centers?
5. What are the achievable cost effective levels of energy savings?
6. What are barriers that increase savings cost and/or reduce the magnitude of achievable savings?


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Use and Virtualization (4 of 5)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Data center cooling space conditioning /humidification
Proliferation of consumer electronics (increased plug loads)
Higher data rates and processing intensity and energy use
Consumer desire to be "green" and reduce embedded & used energy
People more "plugged in" electronically, digital information, social networking
More and cheaper products due to globalization of manufacturing
Production and distribution of cooling in the most energy efficient way
Need to eliminate display partly or completely by routing images directly to eye or the human nervous system
How to create default "OPT out" energy efficiency roadmap
Need open standards for content streaming
Need system wide network power scaling to increase energy efficiency for streaming content
Production of cooling for data centers: high temperature/low lift chillers, high temperature/low lift variable capacity DR equipment plus chillers.
Devices that convert waste heat energy into other usable forms
Human-device interface
"Do not disturb" sign for "OPT out" default
Open source language for energy-using consumer devices
High density heat producing equipment cooling efficiently
Emerson Electric; LBNL; Green Grid
Increase efficiency for data center cooling
EPRI; LBNL
Waste heat conversion to zero or usable energy forms
EPRI; UC Davis; MIT
Optical data transfer to replace metal cables
Intel
Provide "OPT Out" Vs. "OPT In" capability as default in design and use of energy efficiency features
Open source language for energy using devices
LBNL; NREL; Stanford Univ. North Carolina State Univ.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

High density heat producing equipment cooling efficiently. investigate efficient cooling solution for IT equipment other than grounded correction air cooling.

Existing research: Emerson Electric,Lawrence Berkeley National Laboratory (LBNL), Green Grid.

- Subject matter experts in September 2012 referenced immersion cooling research at Emerson Electric.
- *[Summaries of other existing research pending]*

Key research questions:

1. Increasing equipment power densities. Is increasing need for efficient cooling to control temperature?
2. Are there more efficient ways to reject heat, cold plate, radiative cooling, and immersion cooling in dielectric oil baths?

Increase efficiency for data center cooling. What can be done to reduce energy use in cooling data centers? How can the mechanical equipment design and operations be optimized for data center cooling?.

Existing research: Lawrence Berkeley National Laboratory (LBNL), Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. Equipment design and operation for comfort cooling is not optimized for IT equipment cooling in data centers.
2. need high temperature (~60-65F supply temperature Vs ~45F for human comfort application) chillers with low lift.
3. What is the energy saving potential of such equipment and how could these be developed?
4. How can the low grade waste heat generated from IT equipment be used effectively?
5. What are energy efficient solutions and how can these be developed for data centers?

Waste heat conversion to zero or usable energy forms. The development of practical waste heat conversion systems to create alternative energy forms.

Existing research: Electric Power Research Institute (EPRI), Massachusetts Institute of Technology (MIT), University of California Davis.

- *[Summaries of existing research pending]*

Key research questions:

1. What useful waste heat conversions can be practically achieved?
2. What conversion efficiency is achievable?

Continued . . .

Open source language for energy using devices. Energy using devices need to communicate with each other and control systems in a vendor-independent fashion.

Existing research: Lawrence Berkeley National Laboratory (LBNL), National Renewable Energy Laboratory (NREL), Stanford University, North Carolina State University.

- *[Summaries of existing research pending]*

Key research questions:

1. What is the basic set of info that energy devices should tell about itself?
2. What is a standard way for devices to exchange info?

Optical data transfer to replace metal cables. Perform a literature search to identify the manufacturers, national labs, and other organizations involved with R&D on the broader use of optical data transfer, which is more energy efficient than metal cables.

Existing research: Intel.

- *[Summaries of existing research pending]*

Key research questions:

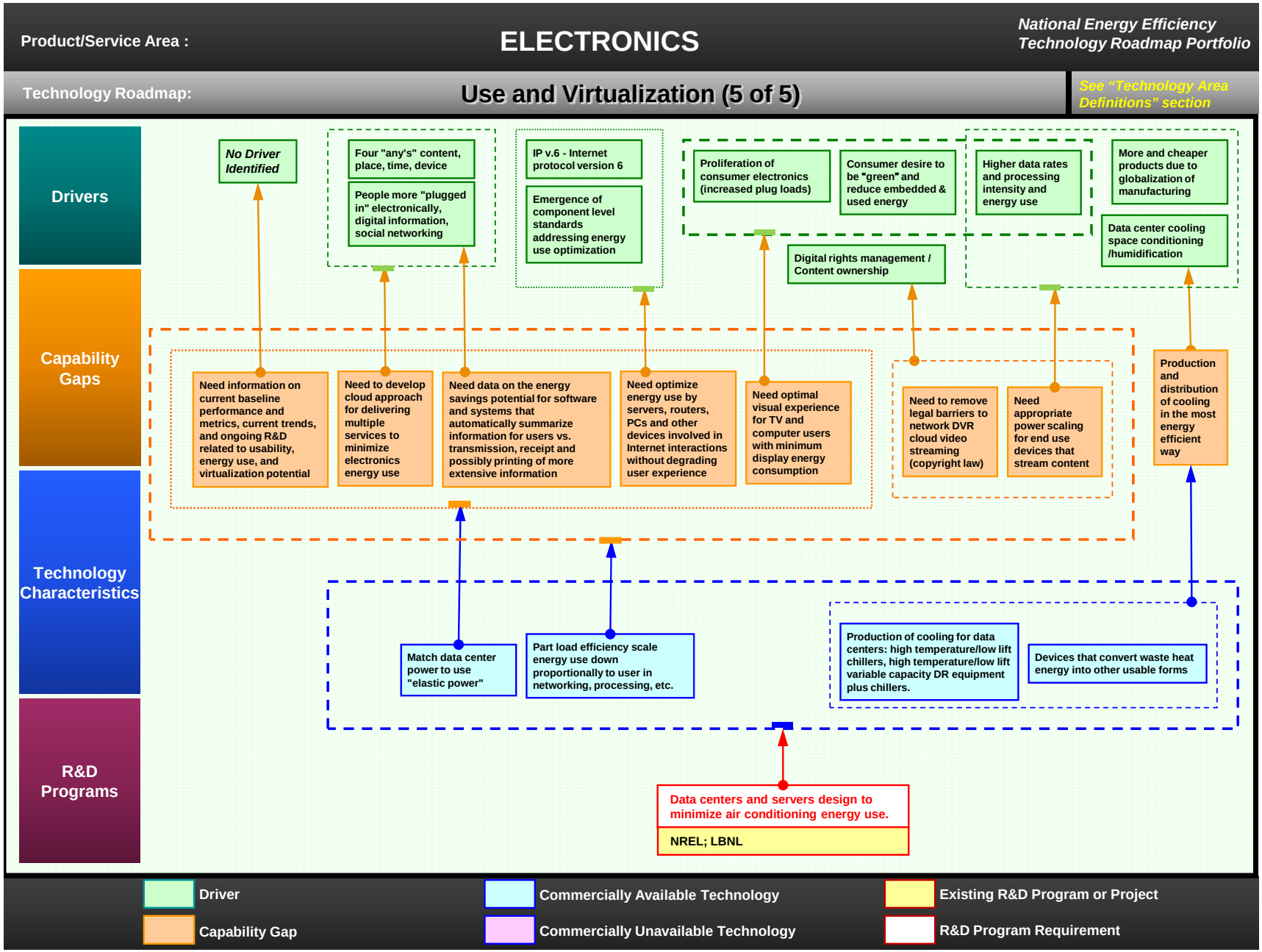
1. Does it take less energy to transmit 1 petabyte (PB) of data over optical fiber compared to metal cable?
2. How much less and is it economically compelling? How does this depend on data density?
3. What would be a way of replacing existing metal cable infrastructure with optical and what would be the magnitude of savings?

Provide "OPT Out" Vs. "OPT In" capability as default in design and use of energy efficiency features. Default features are invariably used and making the energy efficiency and default features will increase it use. Also when developers are developing design/software/apps, they would resolve any issues related to these features will ensure that apps work.

Existing research: None identified.

Key research questions:

1. How do we inculcate the culture of energy efficiency features as default rather than after thought?


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Use and Virtualization (5 of 5)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
No Driver Identified
Four "any's" content, place, time, device
People more "plugged in" electronically, digital information, social networking
IP v.6 - Internet protocol version 6
Emergence of component level standards addressing energy use optimization
Proliferation of consumer electronics (increased plug loads)
Consumer desire to be "green" and reduce embedded & used energy
Higher data rates and processing intensity and energy use
More and cheaper products due to globalization of manufacturing
Data center cooling space conditioning /humidification
Digital rights management / Content ownership
Need information on current baseline performance and metrics, current trends, and ongoing R&D related to usability, energy use, and virtualization potential
Need to develop cloud approach for delivering multiple services to minimize electronics energy use
Need data on the energy savings potential for software and systems that automatically summarize information for users vs. transmission, receipt and possibly printing of more extensive information
Need optimize energy use by servers, routers, PCs and other devices involved in Internet interactions without degrading user experience
Need optimal visual experience for TV and computer users with minimum display energy consumption
Need to remove legal barriers to network DVR cloud video streaming (copyright law)
Need appropriate power scaling for end use devices that stream content
Production and distribution of cooling in the most energy efficient way
Match data center power to use "elastic power"
Part load efficiency scale energy use down proportionally to user in networking, processing, etc.
Production of cooling for data centers: high temperature/low lift chillers, high temperature/low lift variable capacity DR equipment plus chillers.
Devices that convert waste heat energy into other usable forms
Data centers and servers design to minimize air conditioning energy use.
NREL; LBNL
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Data centers and servers design to minimize air conditioning energy use. Goal is to design data centers to maximize heat recovery and minimize space air conditioning energy use.

Existing research: National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

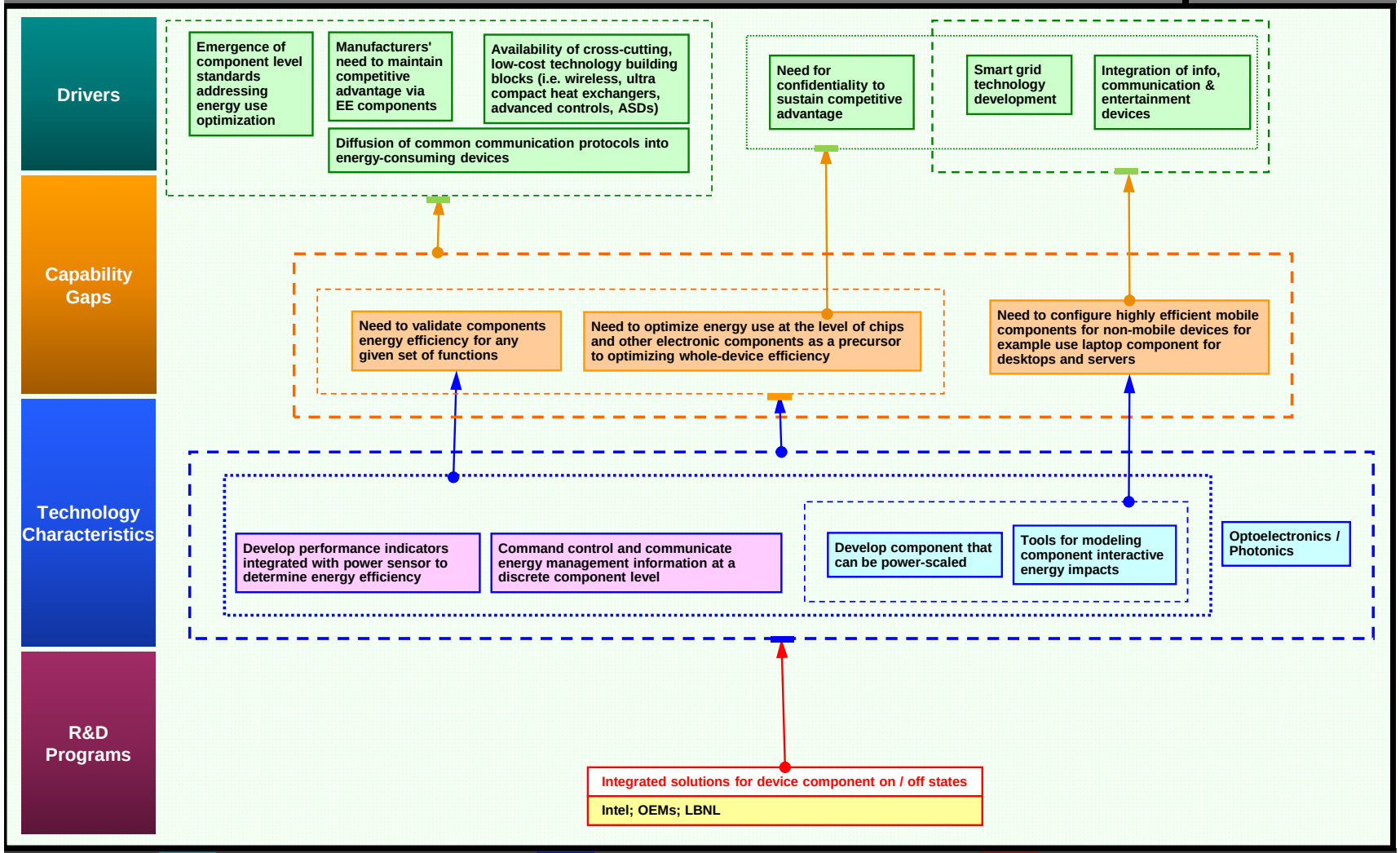
1. What are cost and performance tradeoffs with different air conditioning approaches?
2. What are cost and performance tradeoffs with different heat recovery technologies?
3. How does air conditioning and heat recovery efficiency scale with data center size and location?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Component-Level Efficiency (1 of 3)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Integrated solutions for device component on / off states. Identify and quantify for potentials for high impact products where the reduction of component stand by losses can result in significant savings.

Existing research: Intel, original equipment manufacturers (OEMs), Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

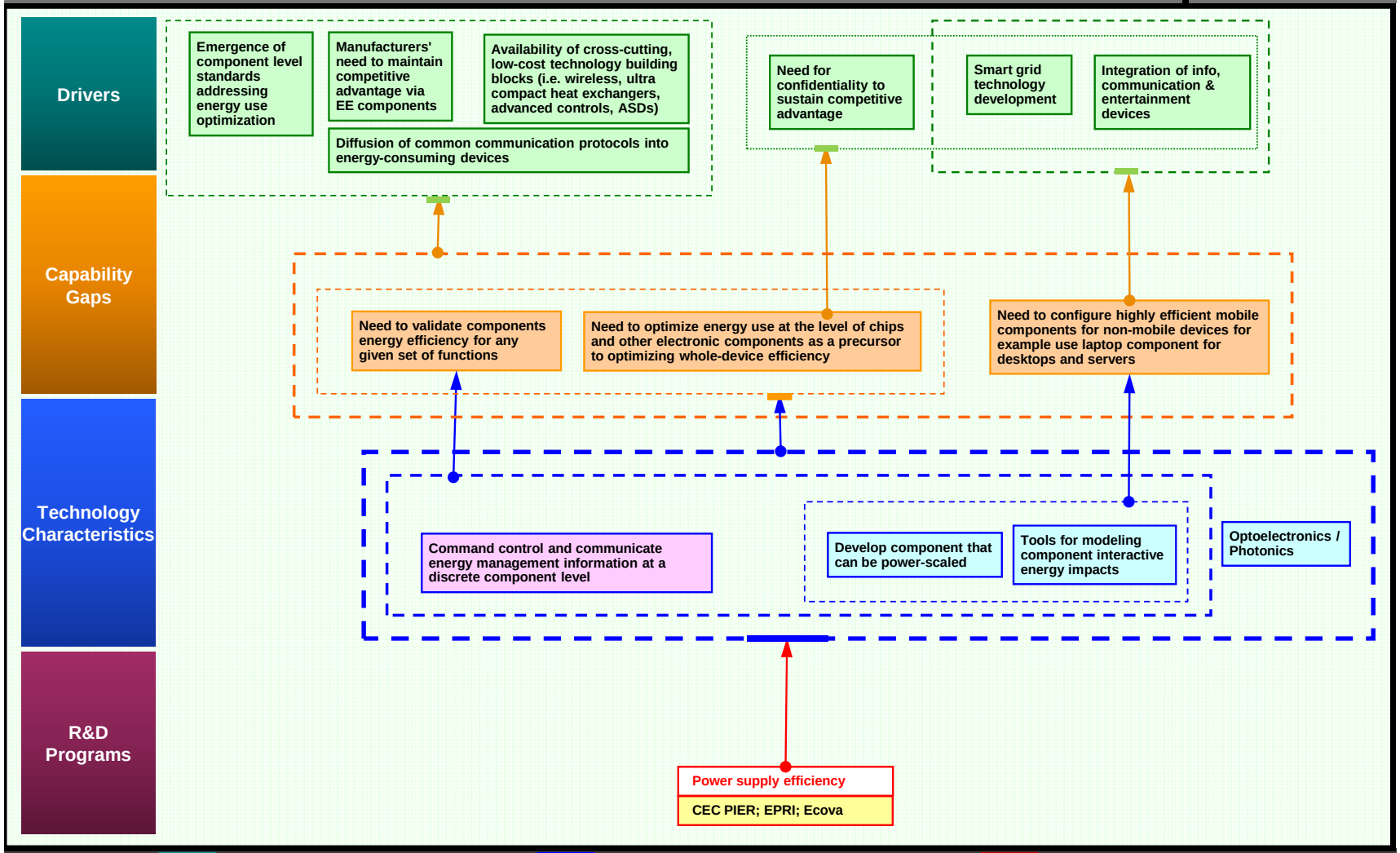
1. Can we identify energy losses mechanism in system?
2. Can we quantify energy saving potential?
3. What is cost/benefit of entering/leaving stand by state?
4. Can we validate through demonstration?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Component-Level Efficiency (2 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

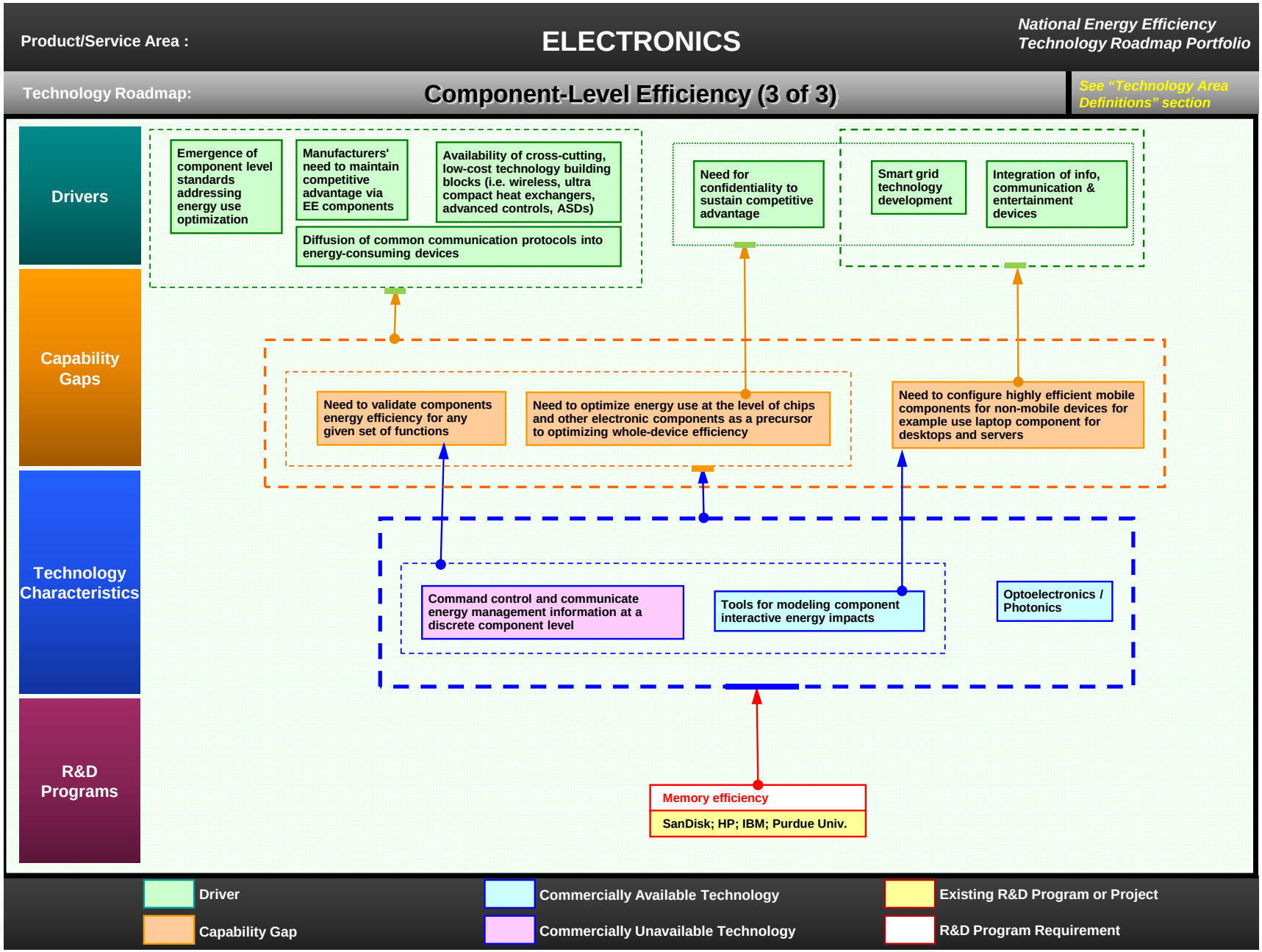
Power supply efficiency. Continue advancing R&D efforts that target power supply efficiency expand beyond computer category.

Existing research: The Electric Power Research Institute (EPRI), Ecova, Inc., and the California Energy Commission's (CEC) Public Interest Energy Research (PIER) program are involved in this work..

- EPRI and Ecova, Inc., (http://www.ecova.com/), with funding from the CED PIER program, have collaborated to create and maintain a website to serve as a forum on current and recently completed R&D on energy efficient power supplies in the "active" or "on" mode (http://www.efficientpowersupplies.org/)
- Ecova, Inc., maintains the website EfficientProducts.org to provide a central location showcasing research on energy efficient consumer products (http://www.efficientproducts.org/index.php).
- An overview of CEC PIER-funded research in consumer and office electronics as of April 2010 can be found at http://www.calit2.uci.edu/uploads/Media/Text/Meister_CECPresentation_ConsumerandOfficeElectronics_Meister.pdf.

Key research questions:

1. Can we develop smart wall warts with load sensing?
2. Can we expand categories under the 80 PLUS voluntary certification program?
3. "Smart" communication protocols to manage charging process or to distinguish AC/DC input?
4. Can we incorporate wide band gap transistors in design?
5. Can we mitigate conducted and radiated emissions?


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Component-Level Efficiency (3 of 3)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Emergence of component level standards addressing energy use optimization
Manufacturers' need to maintain competitive advantage via EE components
Availability of cross-cutting, low-cost technology building blocks (i.e. wireless, ultra compact heat exchangers, advanced controls, ASDs)
Diffusion of common communication protocols into energy-consuming devices
Need for confidentiality to sustain competitive advantage
Smart grid technology development
Integration of info, communication & entertainment devices
Need to validate components energy efficiency for any given set of functions
Need to optimize energy use at the level of chips and other electronic components as a precursor to optimizing whole-device efficiency
Need to configure highly efficient mobile components for non-mobile devices for example use laptop component for desktops and servers
Command control and communicate energy management information at a discrete component level
Tools for modeling component interactive energy impacts
Optoelectronics / Photonics
Memory efficiency
SanDisk; HP; IBM; Purdue Univ.
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Memory efficiency. Continue advancing R&D efforts that target memory efficiency, including development of new, lower-power memory technologies.

Existing research: Subject matter experts report that research is ongoing at SanDisk, IBM, Hewlett-Packard, and other manufacturers. Ongoing research from manufacturers tends largely to be proprietary and, therefore, not thoroughly or consistently reported through companies' web pages. There is also ongoing research at Purdue University.

- SanDisk: http://www.sandisk.com/.
- *[Summaries of other existing research pending.]*

Key research questions:

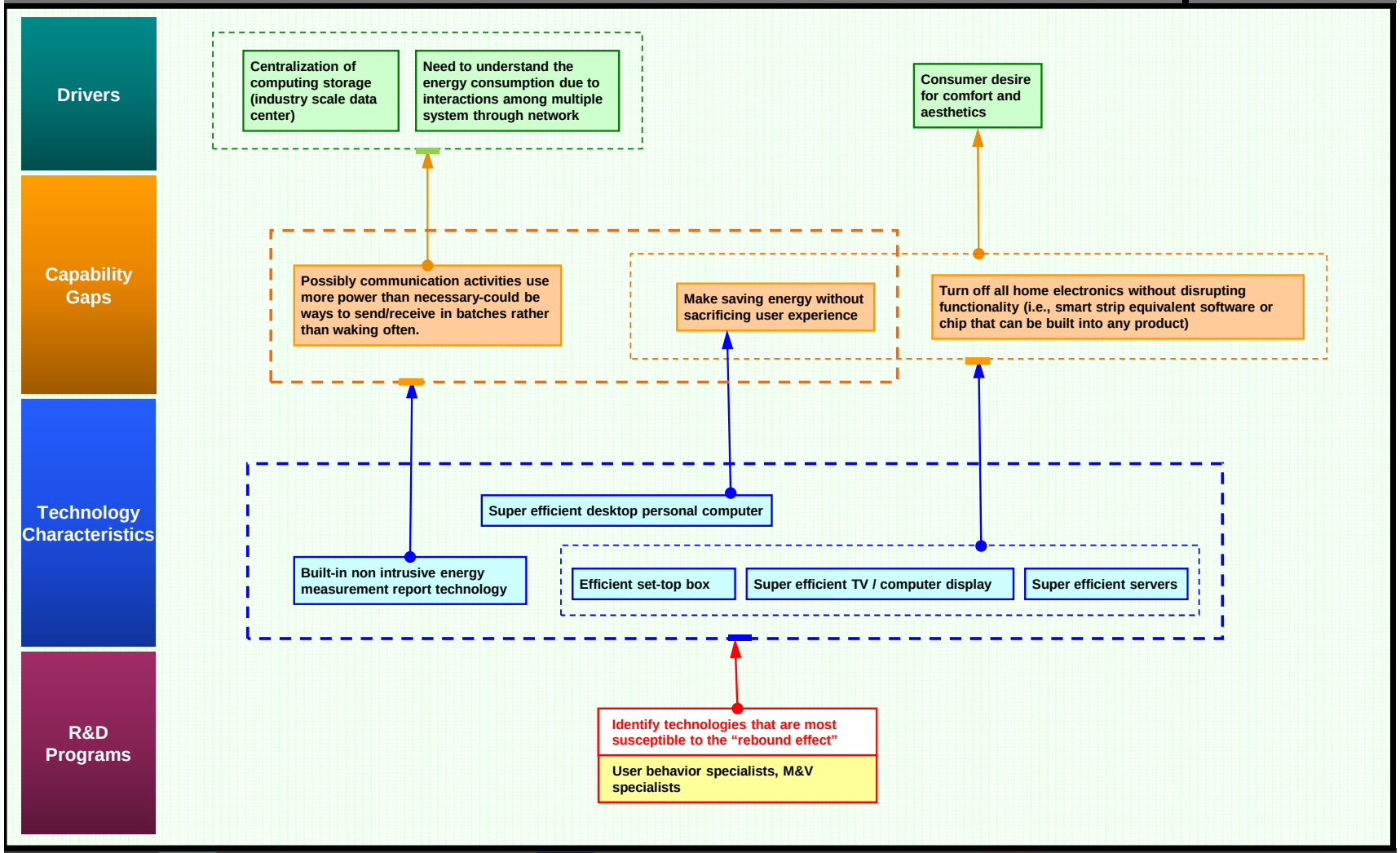
1. Quantify energy savings of alternate memory technologies.
2. Quantify reliability and performance at alternate memory technologies.
3. Quantify costs of alternate memory technologies.
4. Establish benchmark of existing state of the art memory technologies relative to criteria 1-3 above.

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Complete Electronic System (1 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Identify technologies that are most susceptible to the "rebound effect. Perform human factors R&D to determine which combinations of products and users are most likely to cancel out intended energy savings.

Existing research: Stakeholders indicate that research in this area is underway at a institutions that specialize in measurement & verification (M&V) and behavior, but further information about this R&D is not known as of Feb. 2013.

- *[Summaries of existing research pending]*

Key research questions:

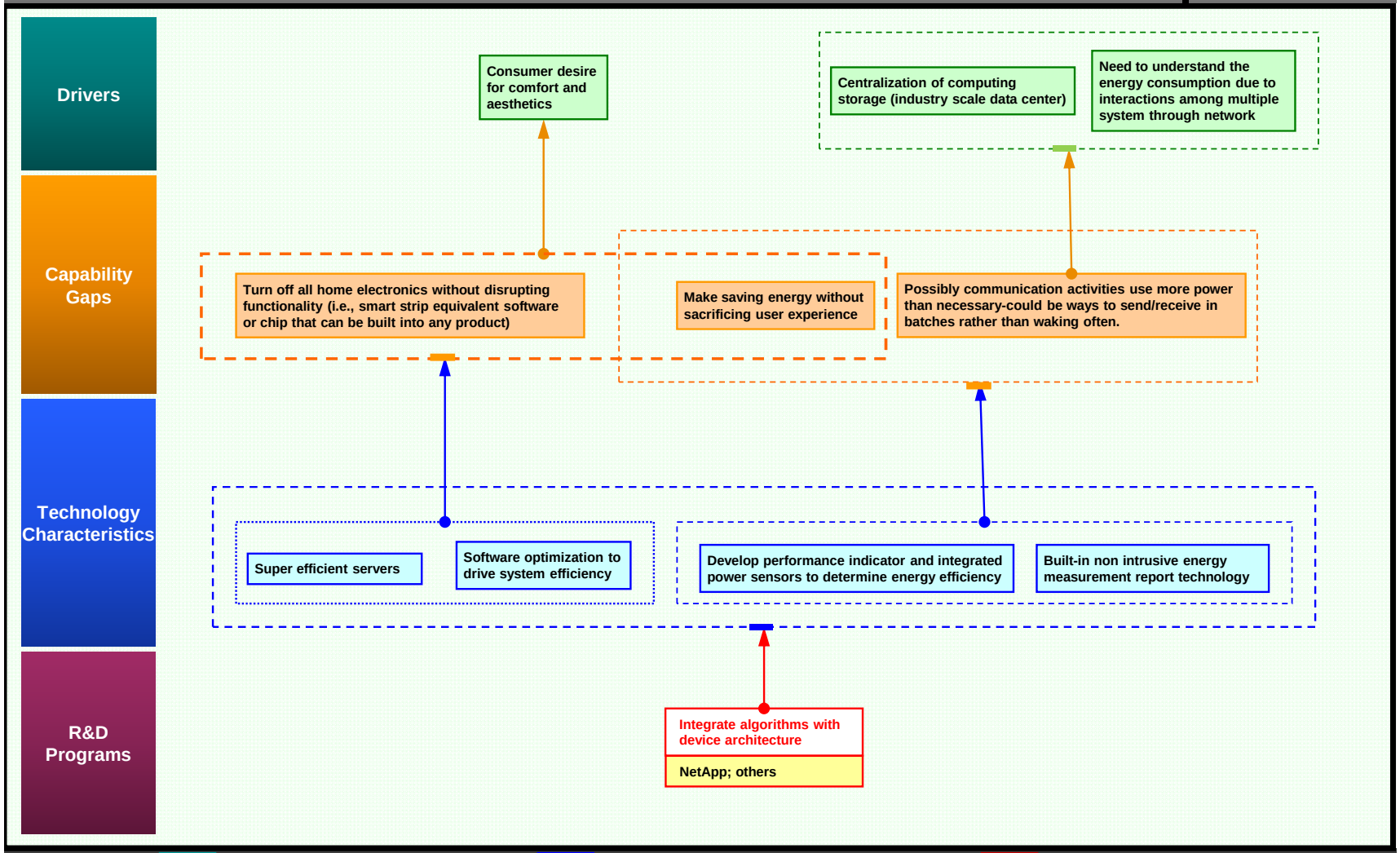
1. How to quantify Everyday Electronic Materials (EEMs) with largest energy saving variances between the baseline and efficient technologies?
2. How to quantify cross-measure influences where "rebound effect" occurs.
3. How to identify primary driver for rebound, based on Everyday Electronic Materials (EEMs)?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Complete Electronic System (2 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Integrate algorithms with device architecture. Measure the energy consumed by servers, storage, and networks for services, select appropriate hardware and software for better energy efficiency.

Existing research: Stakeholders indicate that research in this area is underway at NetApp, Inc. (http://www.netapp.com/us/), but this R&D is not always accessible for collaboration and tends largely to be proprietary and, therefore, not thoroughly or consistently reported through companies' web pages.

- *[Summaries of existing research pending]*

Key research questions:

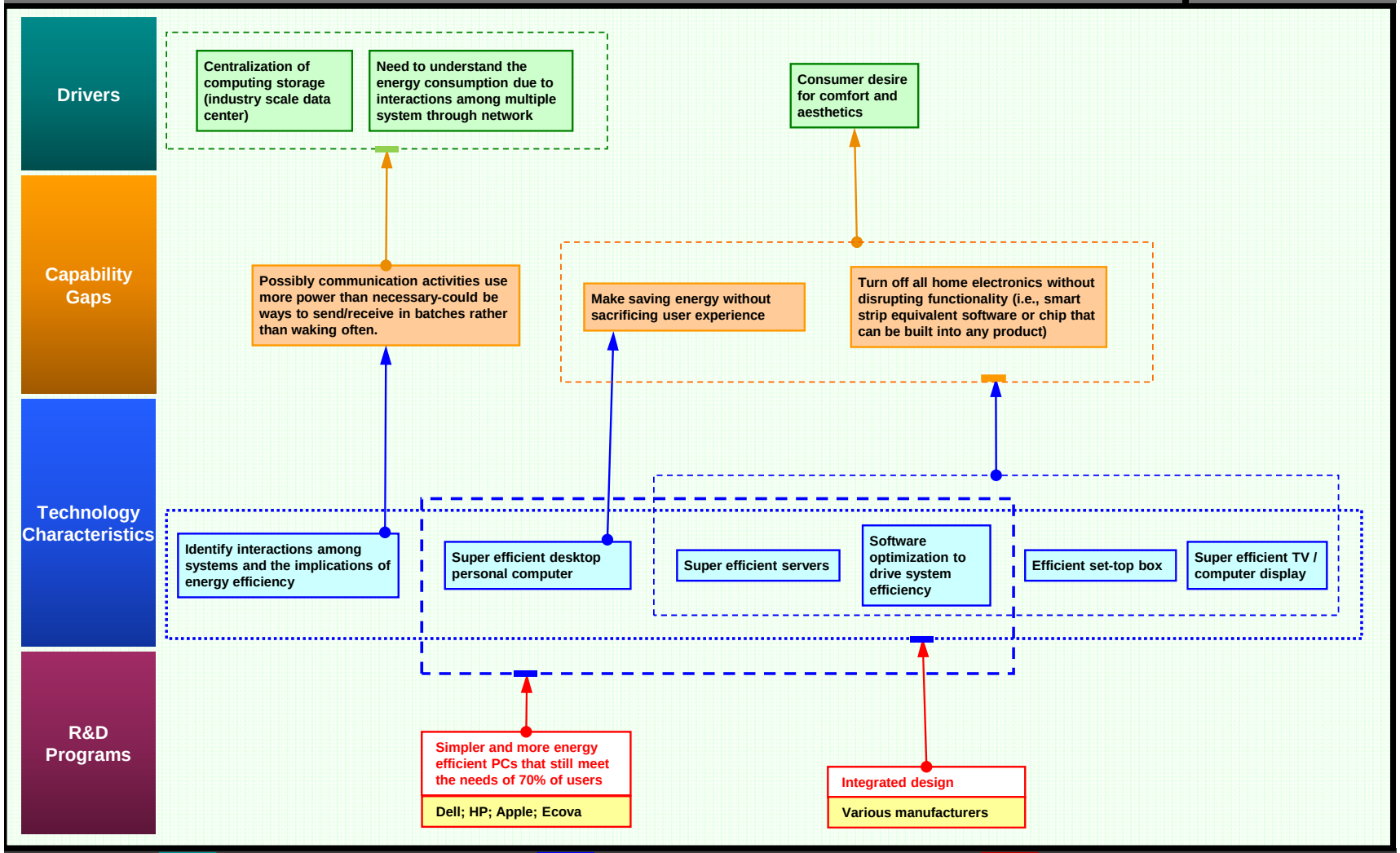
1. How to quantify and minimize the energy consumption for a given service?
2. How to develop a validated methodology for energy efficiency software in distributed systems?
3. How to schedule services for balancing and minimizing consumption in data centers?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Complete Electronic System (3 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Integrated design. Develop tools and approaches to help manufacturers do whole-system designs that achieve ultra-low energy consumption.

Existing research: Stakeholders indicate that research in this area is underway at a variety of television manufacturers, but this R&D is not accessible for collaboration and tends largely to be proprietary and, therefore, not thoroughly or consistently reported through companies' web pages.

- *[Summaries of existing research pending]*

Key research questions:

1. Can we develop consistent methodologies/benchmarking to measure efficiency (open standard)?
2. Can we define categories that are easily bounded with common energy characteristics to enable measurements?

Simpler and more energy efficient PCs that still meet the needs of 70% of users. Explore innovative approaches to reducing energy use by mass-market PCs. Issue challenge to industry for best design.

Existing research: Stakeholders report that research is ongoing at Dell, Hewlett-Packard (HP), Apple, and other manufacturers. Ongoing research from manufacturers tends largely to be proprietary and, therefore, not thoroughly or consistently reported through companies' web pages. There is also ongoing research at Ecova.

- Apple, Inc., reports that every product they sell exceeds ENERGY STAR specifications, and that their goal is to reduce energy use with their laptop and desktop computers while not negatively impacting user experience. Their research includes both hardware and software products, and focuses on three areas: 1) using more efficient power supplies; 2) using components that require less power; 3) using power management software; see http://www.apple.com/environment/energy-efficiency/.
- The work of HP's worldwide research group—HP Labs—spans a range of technical applications and business areas, including cloud computing, security, information analytics, infrastructure, and networking. HP introduced their rp5700 Desktop PC in 2007 that achieved the highest performance rating of the Electronic Products Environmental Assessment Tool (EPEAT) (http://www.epeat.net/) registry and met ENERGY STAR® 4.0 requirements; in April 2010, HP introduced two space-saving and energy-efficient desktop PCs; see http://www.hpl.hp.com/ and http://www.hp.com/hpinfo/newsroom.
- *[Summaries of other existing research pending]*

Key research questions:

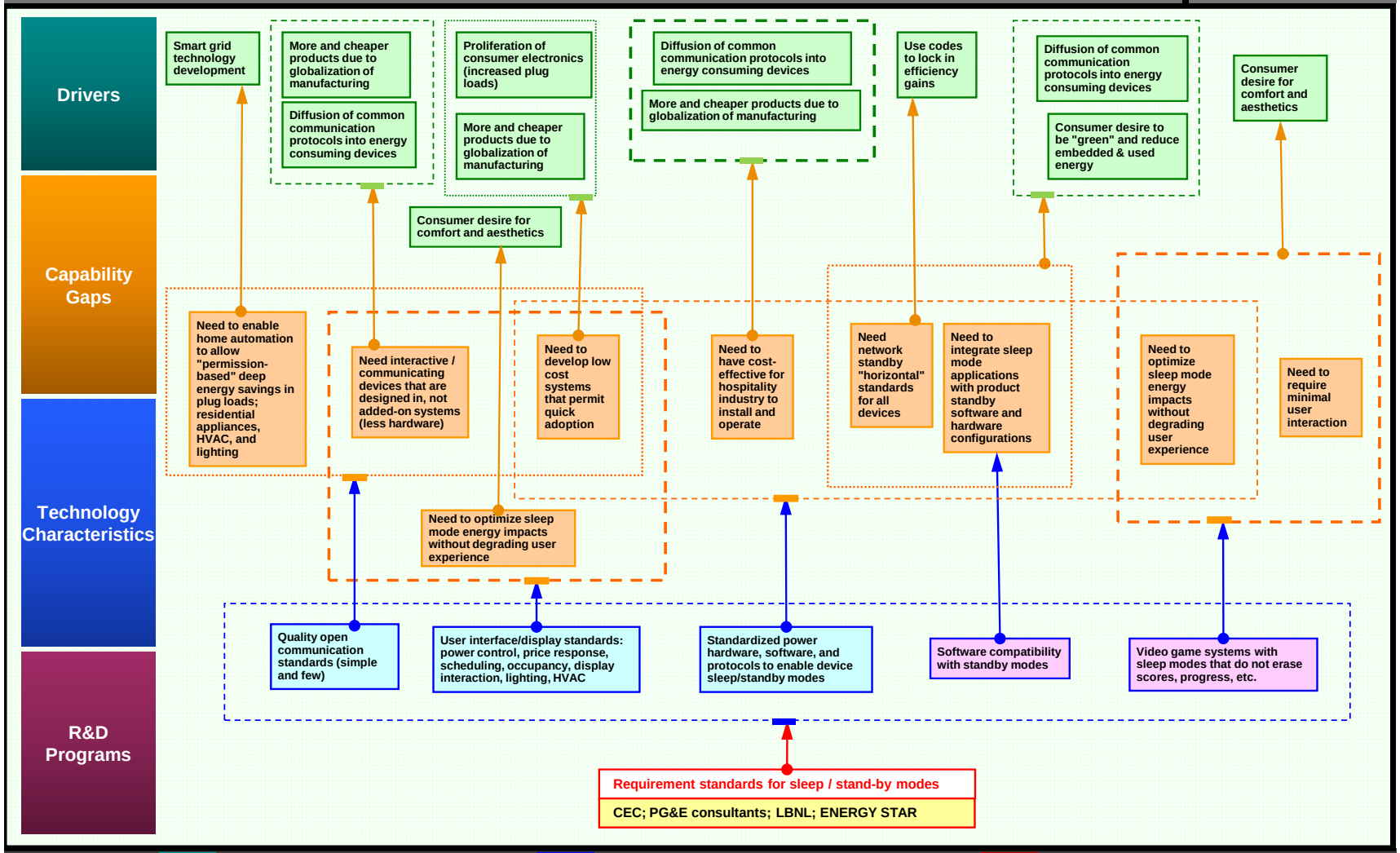
1. Can we develop net zero laptop for a given set of function?
2. What subsystems can be optimized?
3. What components are needed for optimization?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Power Management Control and Communication (1 of 14)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Requirement standards for sleep / stand-by modes. Develop equipment and code-based approaches to eliminating product energy consumption when not in use.

Existing research: Research is ongoing at the California Energy Commission (CEC), Pacific Gas & Electric (PG&E), the Lawrence Berkeley National Laboratory (LBNL), and ENERGY STAR.

- Stakeholders referenced PG&E research in this area, which is likely conducted by the PG&E Emerging Technologies Program. This program does not have its own website, and current contact information is not readily apparent; as of Feb. 2012, attempts continue to track-down this information.
- Ongoing work in this area at the LBNL can be found in Appendix B.
- ENERGY STAR sleep-mode/stand-by standards for computers and electronic equipment can be found at http://www.energystar.gov/index.cfm?c=products.pr_find_es_products.
- *[Summaries of other existing research pending]*

Key research questions:

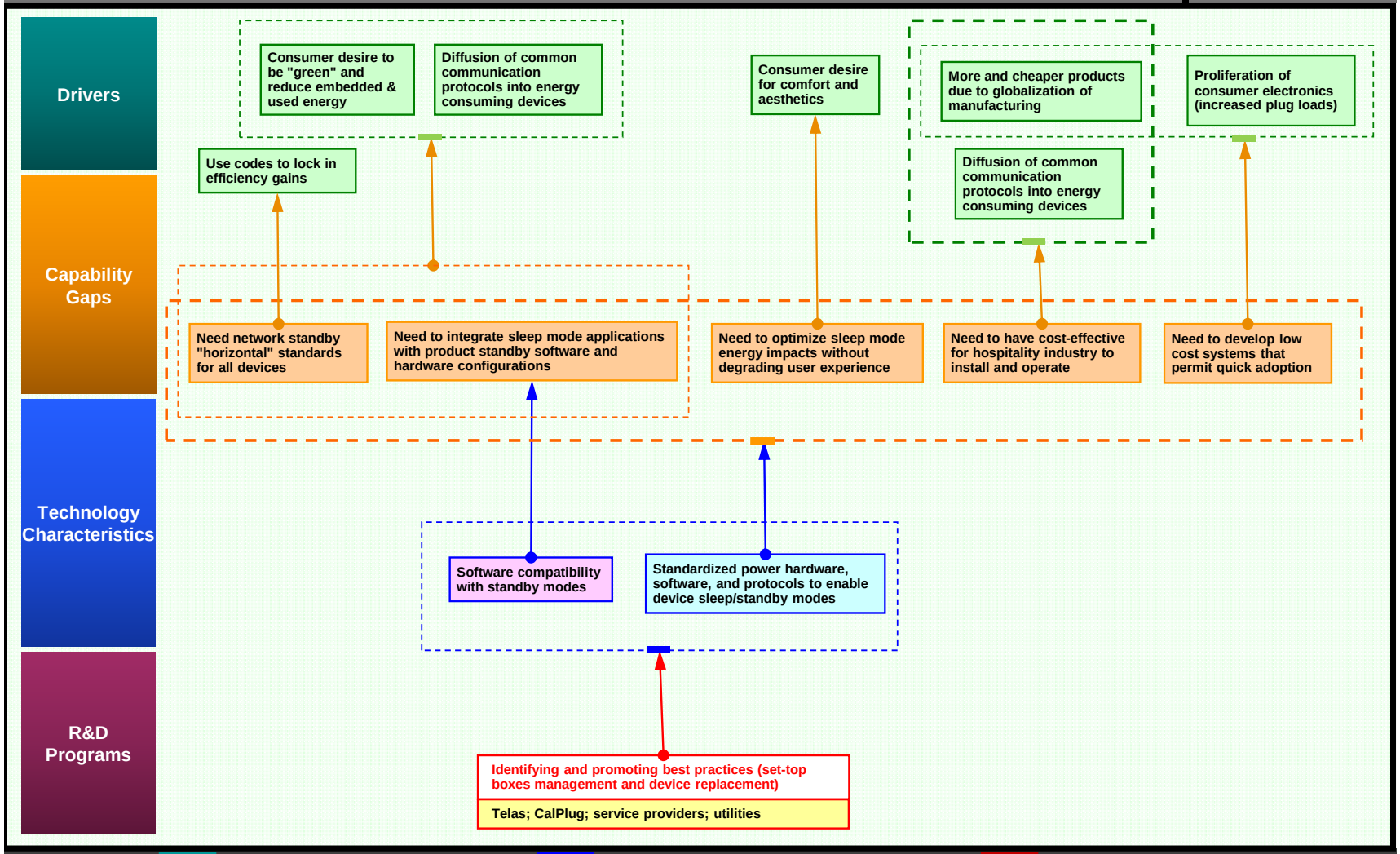
1. How can a product stay aware in a low power state to be powered up when needed?
2. How can a product seamlessly be updated from a low power state (e.g. software update, firmware updates, programs guides)?
3. How does a product know when it can go to sleep? How can a user opt-art?
4. What user interface standard can be used for users to understand power state and how to wake it up?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Power Management Control and Communication (2 of 14)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Identifying and promoting best practices (STB power management and device replacement). Some devices will operate much beyond the time new versions, that are significantly more efficient, are available. What justifications are needed for retirement (recycling and level of energy savings) to occur?.

Existing research: Telas, California Plug Load Research Center (CalPlug), service providers, utilities.

- *[Summaries of existing research pending]*

Key research questions:

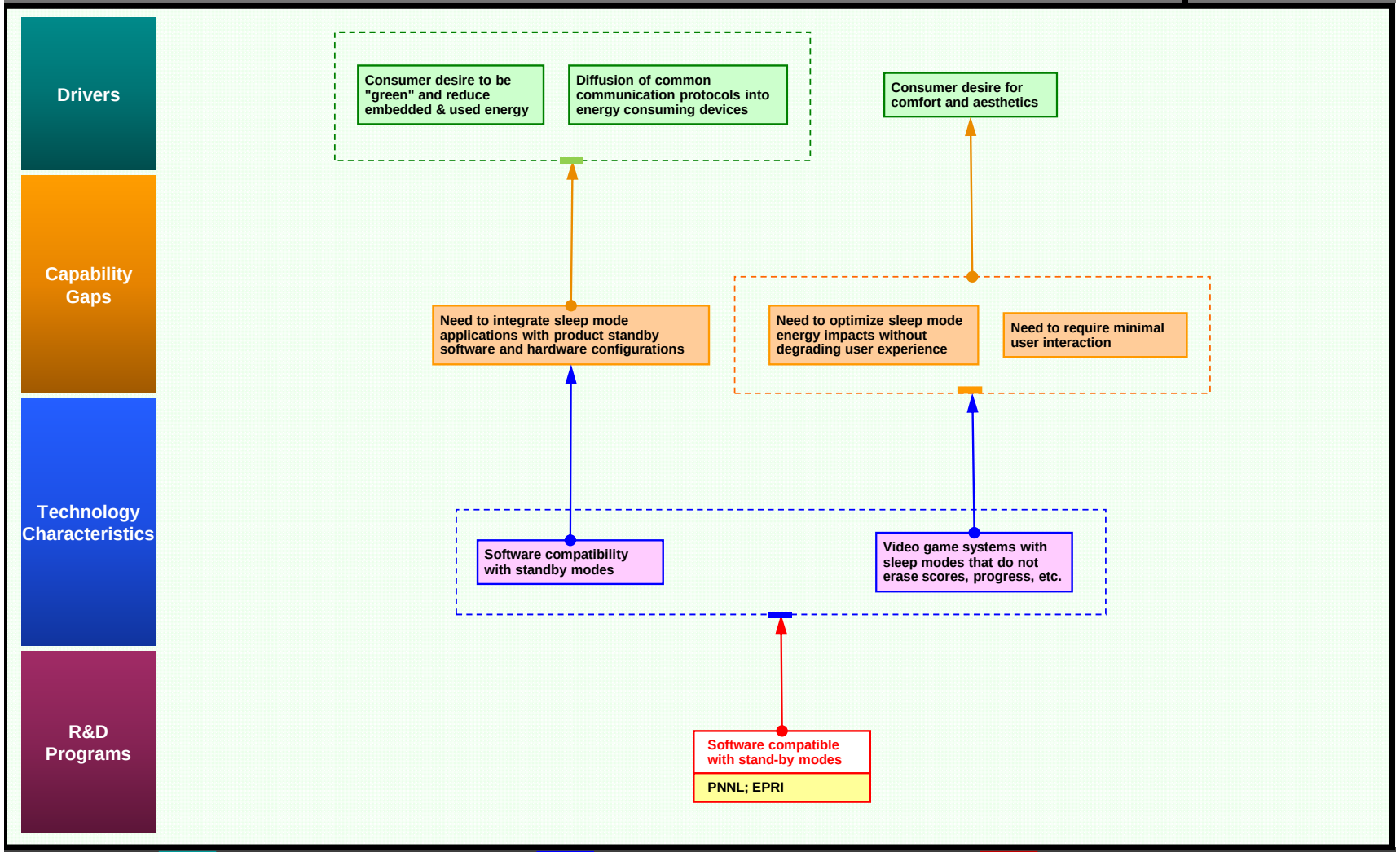
1. What best practices are being used by to save energy (ie. set top boxes) through power management? Identify what and where this is occurring?
2. What incentive levels can be justified (if they can) for a particular device to be retired based on energy savings and repurposing options?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Power Management Control and Communication (3 of 14)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Software compatible with stand-by modes. To facilitate widespread adoption of sleep mode technology, it is essential that the technology serves the needs of end users and network administrators and is also compatible with all commonly used software applications and video games.

Existing research: Pacific Northwest National Laboratory (PNNL), Electric Power Research Institute (EPRI).

- In 2010, EPRI completed a preliminary study on the power consumption of various gaming consoles. The deliverable for this study was a press release, but ongoing related work in this and other areas of electronics components and systems is part of EPRI's End Use Energy Efficiency and Demand Response research (Program 170) and can be found in Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

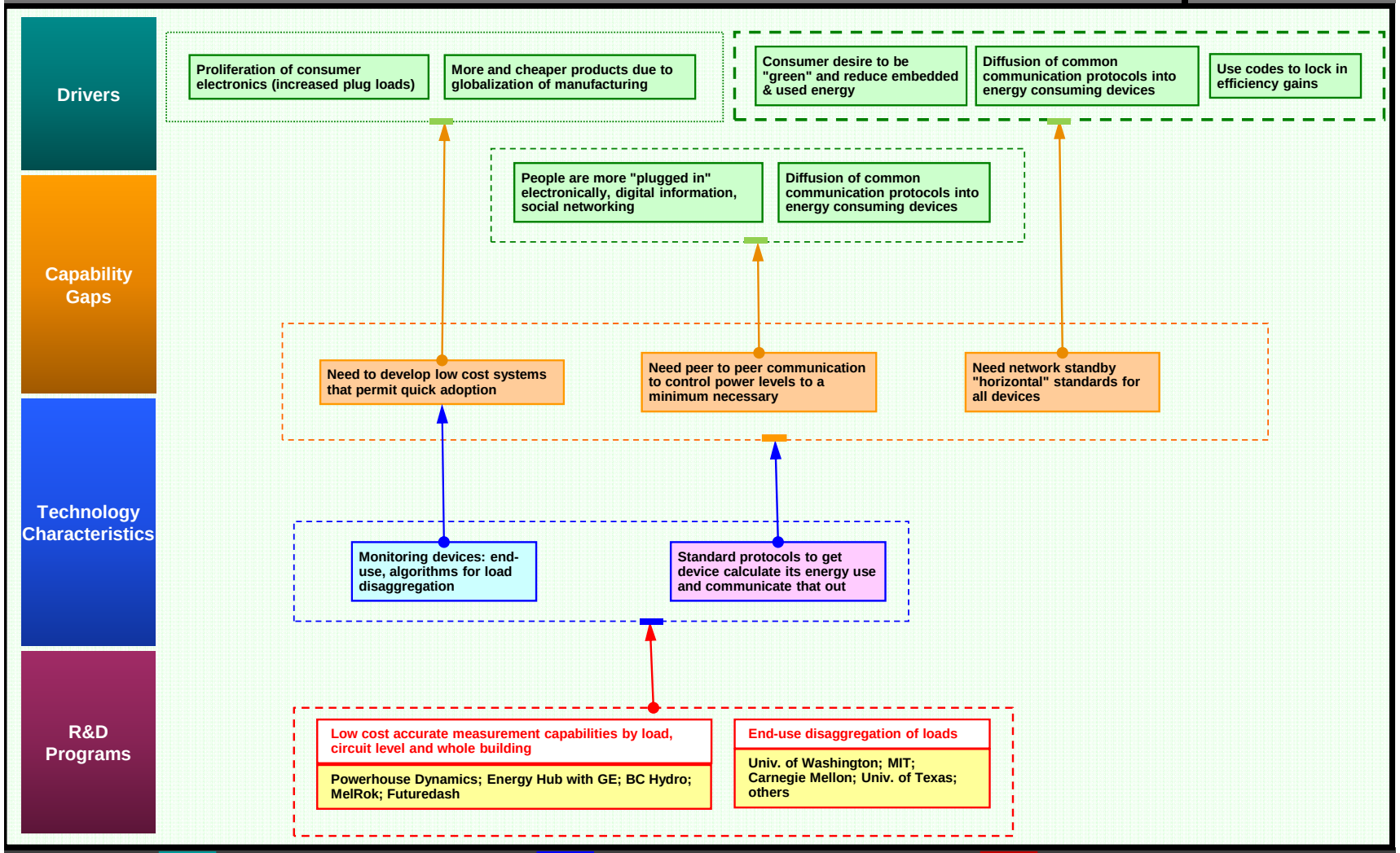
1. Games need sleep mode that save all information so not overridden.
2. Game controls need to be shipped and sleep mode activated.

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Power Management Control and Communication (4 of 14)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Low cost accurate measurement capabilities by load, circuit level and whole building. A simple (to the customer) method of measuring unit energy use is needed to aid our understanding of the device's significance in building energy use. Measurement must be non-intrusive and reasonably accurate. This also serves as a signal to manufacturers.

Existing research: Powerhouse Dynamics, Energy Hub with General Electric (GE), BC Hydro, MelRok, Futuredash.

- EnergyHub: http://www.energyhub.com/.
- eMonitor by Powerhouse Dynamics: http://www.powerhousedynamics.com/.
- BC Hydro's load research group: http://www.bchydro.com/index.html.
- MelRok: http://www.melrok.com/.
- EnergyBuddy by Futuredash: http://www.futuredash.com/energybuddy.
- *[Summaries of existing research pending]*

Key research questions:

1. Determine what is needed via computation capabilities and monitoring of device's state to calculate energy use over time. Protocol for manufactures.
2. Would a standard serve to provide manufactures with what they need to embed capability within device?
3. What software/app requirements are needed to capture device's energy use?
4. How can advanced measurement be used for evaluation of energy efficiency programs in this area?

End-use disaggregation of loads. Development of non-intrusive load monitoring (NILM) methods and tools.

Existing research: University of Washington, Massachusetts Institute of Technology (MIT), Carnegie Mellon University, University of Texas.

- *[Summaries of existing research pending]*

Key research questions:

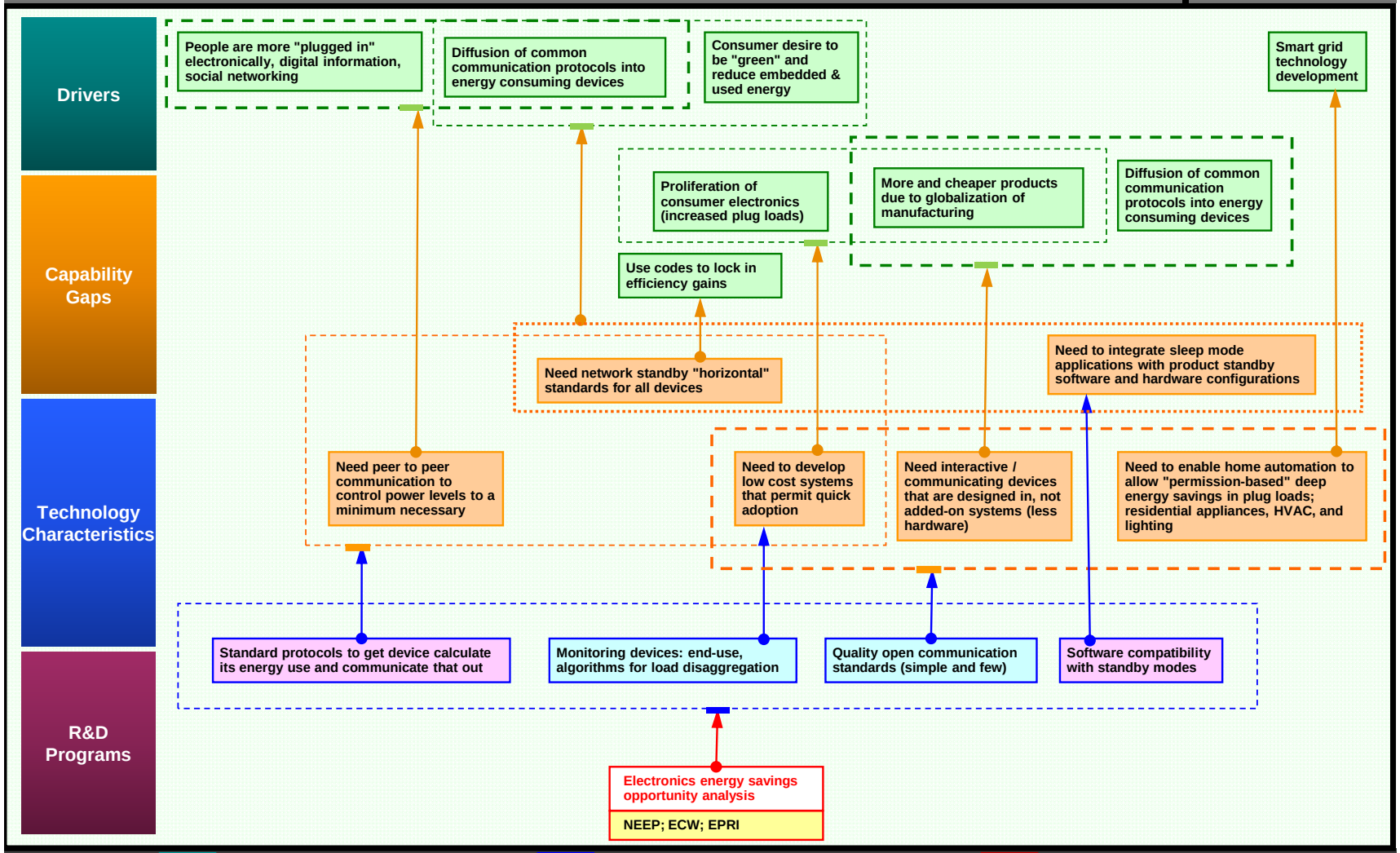
1. Appliance end-use disaggregation (based on circuit – or building – level measurement) algorithm development.
2. Define accuracy and sample interval requirements for various inventory, control, and M&V needs to evaluate available NILM technology against.

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Power Management Control and Communication (5 of 14)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

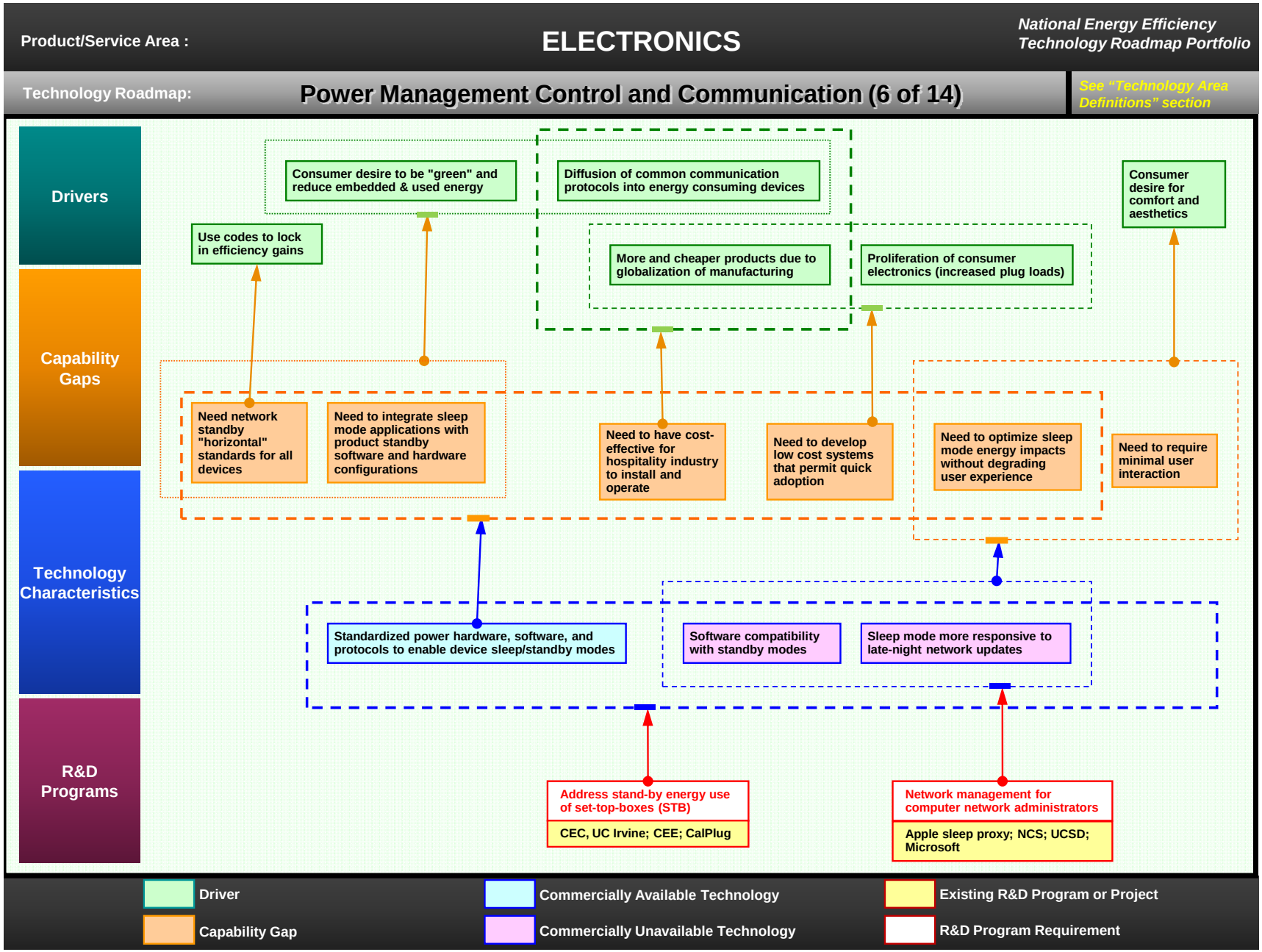
Electronics energy savings opportunity analysis. Analysis of plug-load including changing, mobile, and off-grid devices savings opportunities and cost/benefit characterization to develop effective strategies for active energy management and purchase/replacement decisions.

Existing research: Energy Efficiency Partnerships (NEEP), ,Energy Center of Wisconsin (ECW), Electric Power Research Institute (EPRI).

- ECW: http://www.ecw.org/.
- NEEP: http://www.neep.org/.
- *[Summaries of existing research pending]*

Key research questions:

1. Need detailed inventory of plug loads and analysis of energy savings opportunities for individual devices.
2. What is the total energy use attributed to plug loads? (all electronics, all miscellaneous devices; all other plug tools)
3. Useful life assessment and data on typical replacement timelines. How often are devices replaced (for each type of device)? How often should they be replaced? What is really happening to legacy devices (recycled or re-used in the kids' room)?


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Power Management Control and Communication (6 of 14)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Consumer desire to be "green" and reduce embedded & used energy
Diffusion of common communication protocols into energy consuming devices
Consumer desire for comfort and aesthetics
Use codes to lock in efficiency gains
More and cheaper products due to globalization of manufacturing
Proliferation of consumer electronics (increased plug loads)
Need network standby "horizontal" standards for all devices
Need to integrate sleep mode applications with product standby software and hardware configurations
Need to have cost-effective for hospitality industry to install and operate
Need to develop low cost systems that permit quick adoption
Need to optimize sleep mode energy impacts without degrading user experience
Need to require minimal user interaction
Standardized power hardware, software, and protocols to enable device sleep/standby modes
Software compatibility with standby modes
Sleep mode more responsive to late-night network updates
Address stand-by energy use of set-top-boxes (STB)
CEC, UC Irvine; CEE; CalPlug
Network management for computer network administrators
Apple sleep proxy; NCS; UCSD; Microsoft
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Network management for computer network administrators. To facilitate widespread adoption of sleep mode technology, it's not enough that it works well with end users. Sleep mode also needs to meet the needs of network administrators; otherwise, they will not support (or will even disallow) its use. For example, sleep mode must become more responsive to late night network admin updates.

Existing research: Researchers at U.C. San Diego (UCSD) and at Microsoft are working in this area; others include Apple sleep proxy and NCS.

- Researchers at UCSD developed their "SleepServer" software in 2009 to reduce personal computer energy consumption within enterprise environments by hosting a light-weight image of each PC on the server that can allow the individual PCs to remain in sleep mode longer, but still remain accessible for waking. This product is currently being refined for wider applicability and commercialization. More information about this project in Appendix B.
- Microsoft's "sleep proxy" allows PCs to remain in sleep mode, on average, about 50% more of the time without sacrificing employee or IT accessibility. More information about this project in Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. Conduct in-depth survey of network administrators segmented by network size and sector to determine their needs that may conflict with existing sleep modes.
2. How do networks administrators needs align with features and functions of desktop, laptop, net books, etc. computers available today?
3. How to integrate changes or enhancements to computer sleep modes that overcome existing barriers?
4. How to move forward to incorporate the admin's needs and sleep mode enhancements?

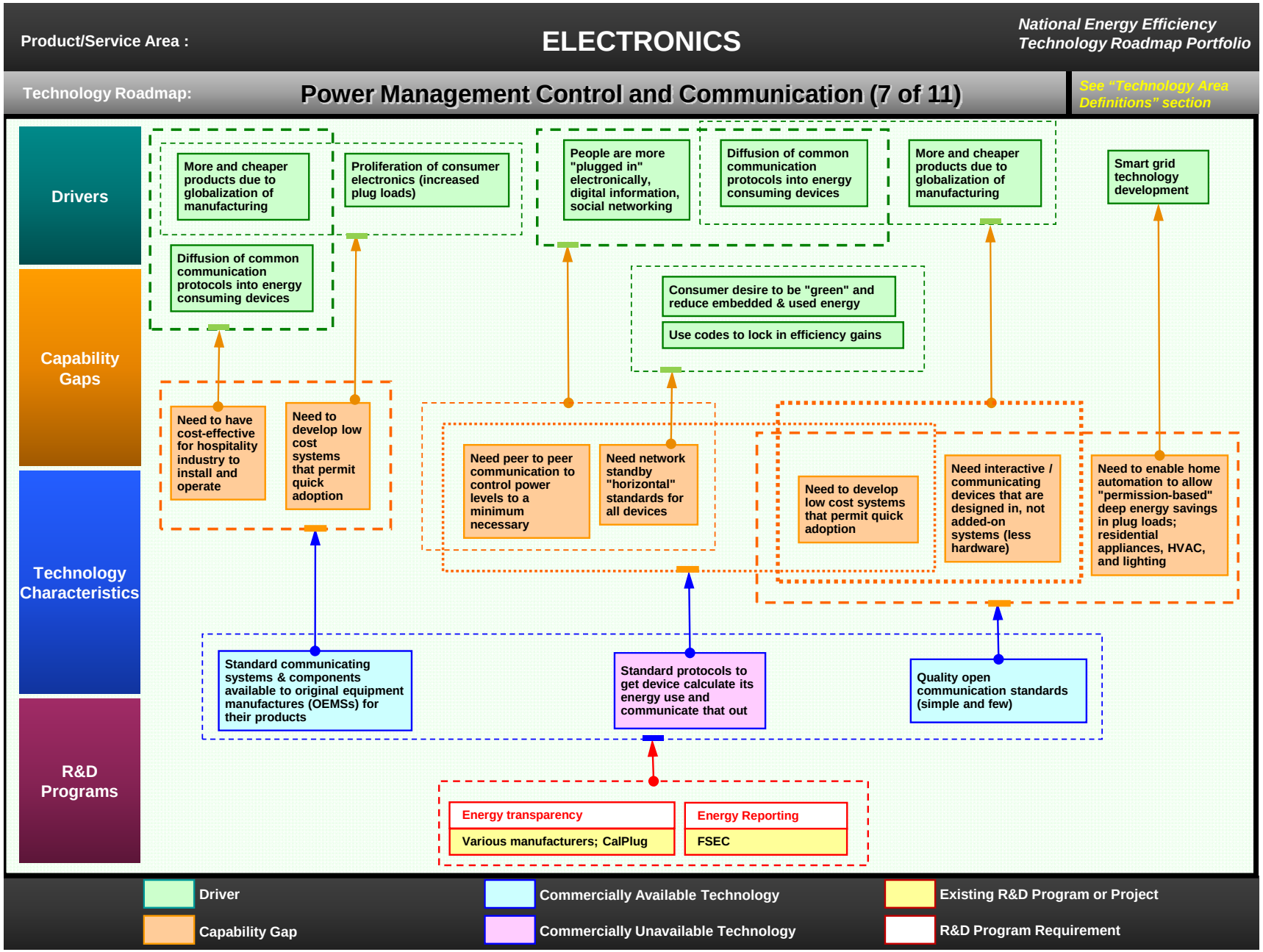
Address stand-by energy use of STBs. Facilitate and monitor industry progress towards low-energy sleep modes for STB. Potential for dramatic energy reductions in the U.S. households in 5 years.

Existing research: California Energy Commission (CEC), University of California Irvine, Consortium for Energy Efficiency (CEE).

- Subject matter experts in September 2012 referred to the work of CEE's Electronics Committee.
- *[Summaries of existing research pending]*

Key research questions:

1. What is industry progress towards low-energy stand-by for STB?
2. Can avoiding STB cable card be used to drop STB stand-by power to lower 10 Watts?
3. What can be done to assist industry in reaching a successful and timely result?
4. Monitoring or pilot testing of low-energy STBs?
5. Can we eliminate STBs by removing the legal barriers to network our implementation?


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Power Management Control and Communication (7 of 11)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
More and cheaper products due to globalization of manufacturing
Proliferation of consumer electronics (increased plug loads)
People are more "plugged in" electronically, digital information, social networking
Diffusion of common communication protocols into energy consuming devices
More and cheaper products due to globalization of manufacturing
Smart grid technology development
Diffusion of common communication protocols into energy consuming devices
Consumer desire to be "green" and reduce embedded & used energy
Use codes to lock in efficiency gains
Need to have cost-effective for hospitality industry to install and operate
Need to develop low cost systems that permit quick adoption
Need peer to peer communication to control power levels to a minimum necessary
Need network standby "horizontal" standards for all devices
Need to develop low cost systems that permit quick adoption
Need interactive / communicating devices that are designed in, not added-on systems (less hardware)
Need to enable home automation to allow "permission-based" deep energy savings in plug loads; residential appliances, HVAC, and lighting
Standard communicating systems & components available to original equipment manufactures (OEMSs) for their products
Standard protocols to get device calculate its energy use and communicate that out
Quality open communication standards (simple and few)
Energy transparency
Various manufacturers; CalPlug
Energy Reporting
FSEC
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Energy transparency. Create technologies and policy structures so that actual energy use of devices is available to building occupants, owners, manufacturers, regulators, researches, and policy analysts.

Existing research: Various manufacturers, California Plug Load Research Center (CalPlug).

- CalPlug: http://calplug.uci.edu/.
- *[Summaries of existing research pending]*

Key research questions:

1. What mechanisms exist to report energy use to network?
2. How could this be exported outside the building for general use? What is needed to assure privacy and security?
3. How can this information be used by above stakeholders?

Energy Reporting. Identify needs for protocols that report energy use (and related info) of device to network. Identify existing protocols (or ones in development) that do this and evaluate for quality, completeness, application scope, etc. Revise standards as needed. Identify preferred standards.

Existing research: Florida Solar Energy Center (FSEC).

- *[Summaries of existing research pending]*

Key research questions:

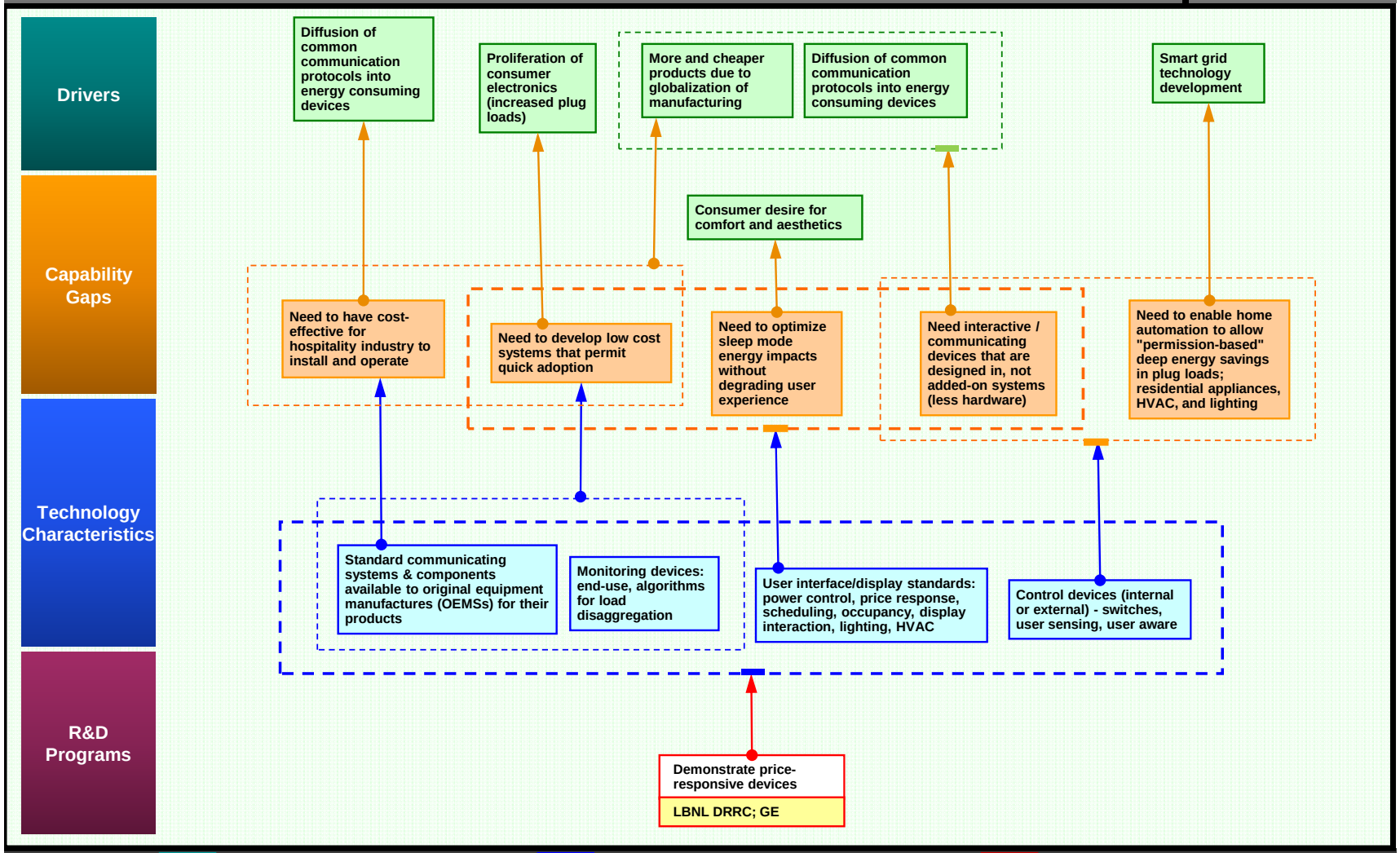
1. What needs to be reported?
2. What protocols are relevant?
3. What protocols are there?
4. How to fill them?
5. Can data exchange in a standardized format be used to foster information in energy feedback, reporting and control?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Power Management Control and Communication (8 of 14)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

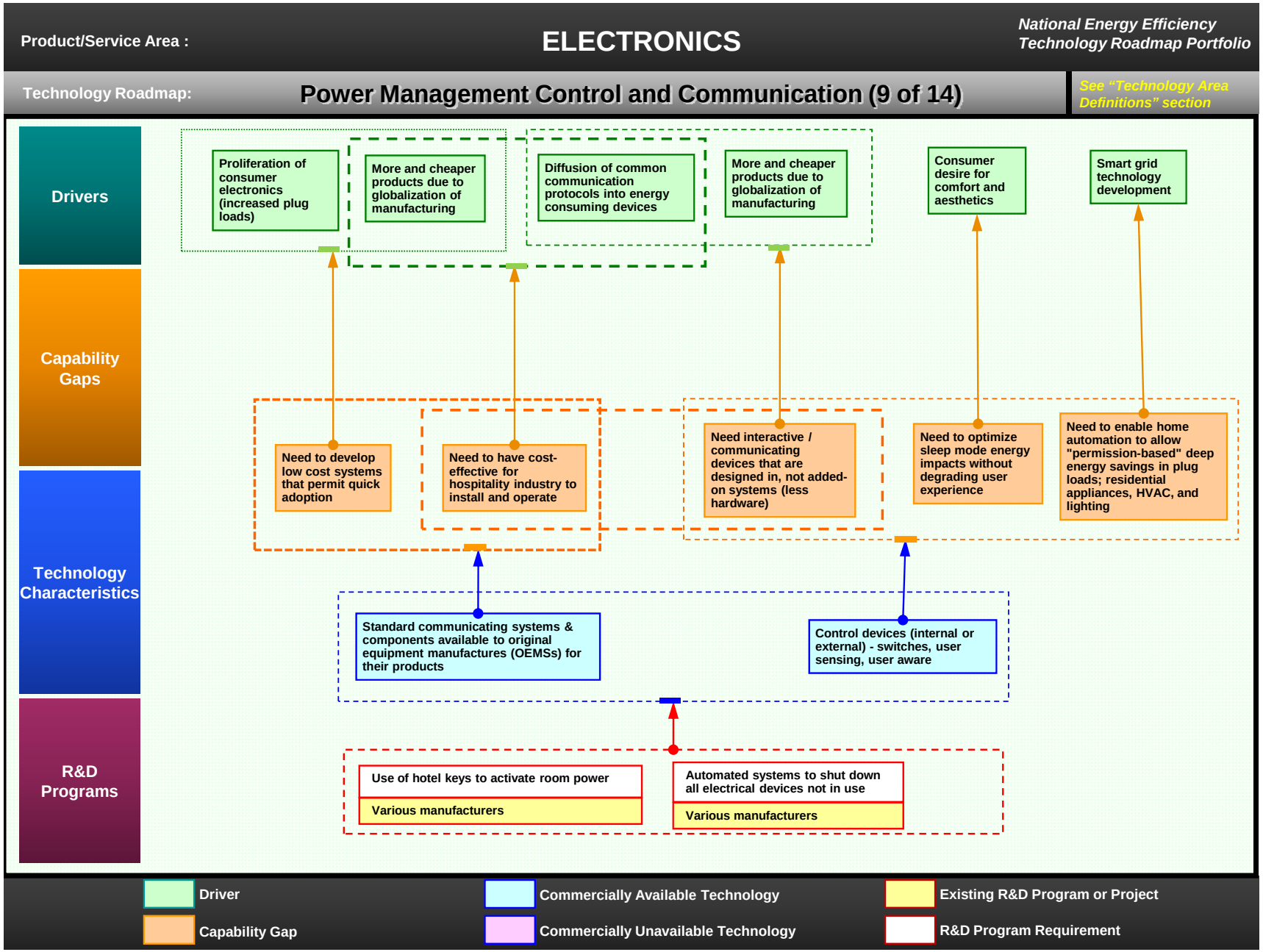
Demonstrate price-responsive devices. Modify electronic devices (e.g. PC, monitor, printer, etc) to be able to receive dynamic prize signals over network and alter behavior in response. Also, do other devices such as refrigerator, lights.

Existing research: Lawrence Berkeley National Laboratory (LBNL) Demand Response Research Center (DRRC), General Electric (GE).

- DRRC: http://drrc.lbl.gov/.
- *[Summaries of existing research pending]*

Key research questions:

1. How can price signals be relayed within a building?
2. What can different price signals do to alter their energy use patterns?
3. What algorithms work well to determine operator?
4. Does it work?
5. Does it add hardware cost to the product?


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Power Management Control and Communication (9 of 14)
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Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Proliferation of consumer electronics (increased plug loads)
More and cheaper products due to globalization of manufacturing
Diffusion of common communication protocols into energy consuming devices
More and cheaper products due to globalization of manufacturing
Consumer desire for comfort and aesthetics
Smart grid technology development
Need to develop low cost systems that permit quick adoption
Need to have cost-effective for hospitality industry to install and operate
Need interactive / communicating devices that are designed in, not added-on systems (less hardware)
Need to optimize sleep mode energy impacts without degrading user experience
Need to enable home automation to allow "permission-based" deep energy savings in plug loads; residential appliances, HVAC, and lighting
Standard communicating systems & components available to original equipment manufactures (OEMSs) for their products
Control devices (internal or external) - switches, user sensing, user aware
Use of hotel keys to activate room power
Various manufacturers
Automated systems to shut down all electrical devices not in use
Various manufacturers
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Use of hotel keys to activate room power. Continue advancing key-based systems that disable lighting, HVAC and other energy uses in hotel rooms when not occupied.

Existing research: Various manufacturers.

- Madison Gas and Electric of Wisconsin has compiled an overview of the potential benefits associated with hotel room automation systems: http://www.mge.com/business/saving/madison/PA_63.html. They have also collated links to nineteen automation controls manufacturers (http://www.mge.com/business/saving/madison/PA_manufacturers.html#PA63).

Key research questions:

1. Questions not yet specified.

Automated systems to shut down all electrical devices not in use. Stakeholders indicate that various products are already equipped with this functionality, but that there is a need to advance current best practices for products that turn themselves off when not in use.

Existing research: Various manufacturers.

- *[Summaries of existing research pending]*

Key research questions:

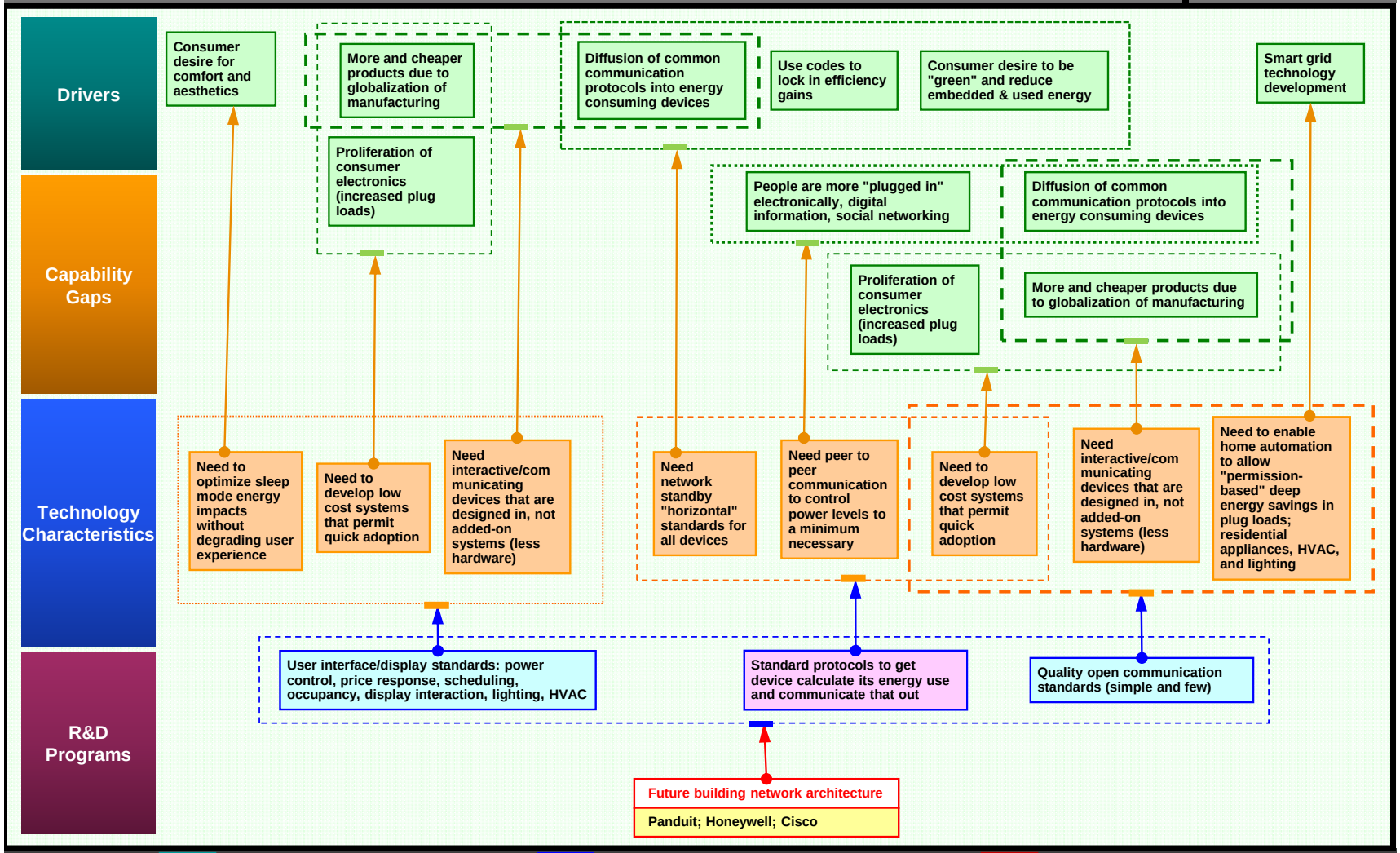
1. Questions not yet specified.

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Power Management Control and Communication (10 of 14)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Future building network architecture. Describe possible approaches to overall structure of networking among all energy-using devices in buildings. Consider all layers of communication. Consider centralized, distributed, and hybrid architecture. Can a standardized protocol be agreed upon?.

Existing research: Panduit, Honeywell, Cisco.

- *[Summaries of* existing *research pending]*

Key research questions:

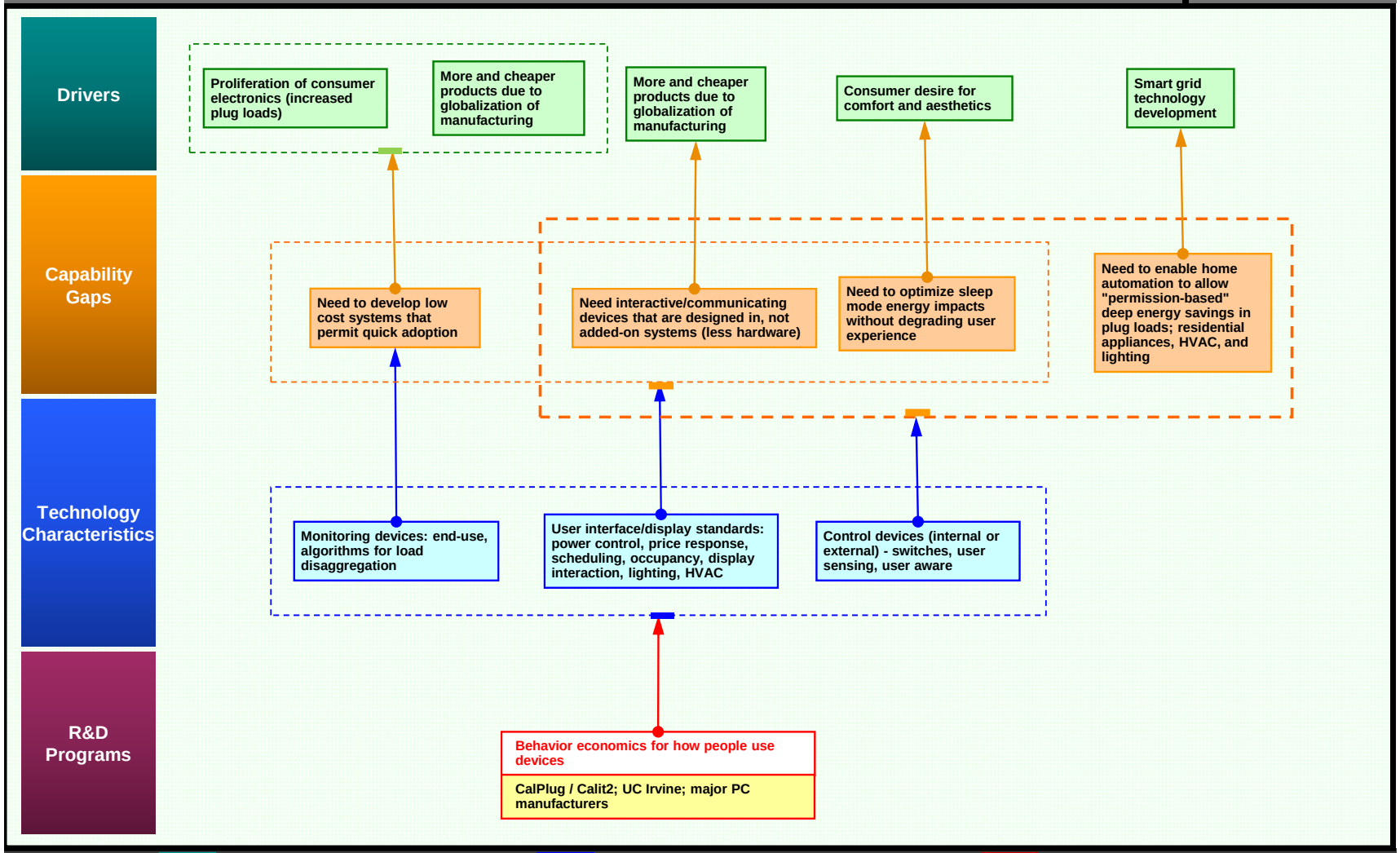
1. What are system designs to consider?
2. What are advantages and disadvantages of each?
3. What pieces of this already exist?
4. What is "ideal" architecture?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Power Management Control and Communication (11 of 14)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

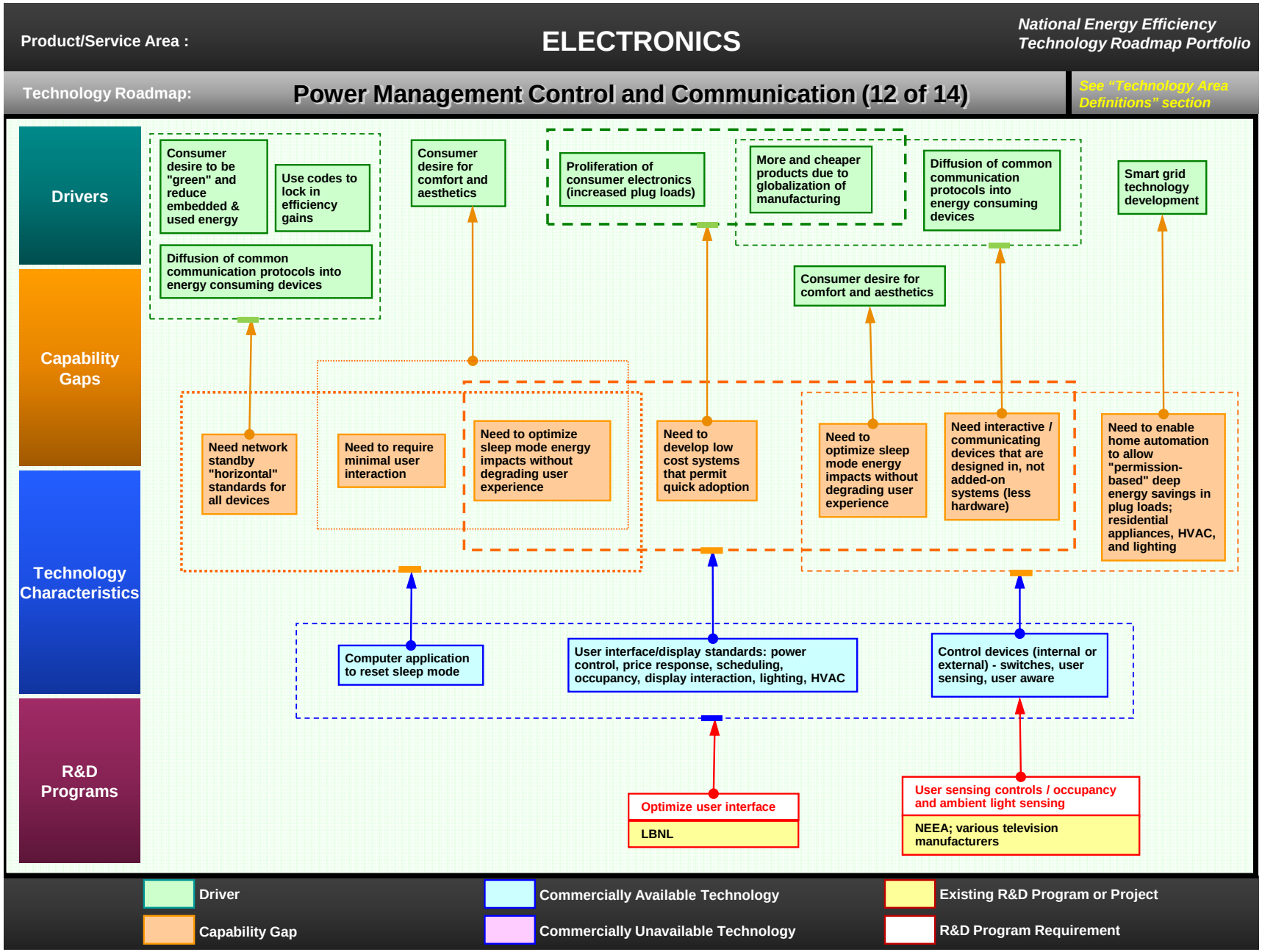
Behavior economics for how people use devices. To facilitate widespread adoption of sleep-mode technology, study the way the most common user groups interact with electronic devices so the sleep-mode technology will be compatible with their behavior.

Existing research: California Plug Load Research Center (CalPlug) with California Institute for Telecommunications and Information Technology (CALIT2), University of California Irvine, Major PC manufacturers.

- CalPlug:http://calplug.uci.edu/.
- CALIT2: http://www.calit2.net/.
- *[Summaries of existing research pending]*

Key research questions:

1. When is putting devices into low power modes acceptable to users?
2. How do users "wake" devices? How do they want to?
3. Which devices do people have connected together? Which devices do they use to control other devices?


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Power Management Control and Communication (12 of 14)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Consumer desire to be "green" and reduce embedded & used energy
Use codes to lock in efficiency gains
Diffusion of common communication protocols into energy consuming devices
Consumer desire for comfort and aesthetics
Proliferation of consumer electronics (increased plug loads)
More and cheaper products due to globalization of manufacturing
Diffusion of common communication protocols into energy consuming devices
Smart grid technology development
Consumer desire for comfort and aesthetics
Need network standby "horizontal" standards for all devices
Need to require minimal user interaction
Need to optimize sleep mode energy impacts without degrading user experience
Need to develop low cost systems that permit quick adoption
Need to optimize sleep mode energy impacts without degrading user experience
Need interactive / communicating devices that are designed in, not added-on systems (less hardware)
Need to enable home automation to allow "permission-based" deep energy savings in plug loads; residential appliances, HVAC, and lighting
Computer application to reset sleep mode
User interface/display standards: power control, price response, scheduling, occupancy, display interaction, lighting, HVAC
Control devices (internal or external) - switches, user sensing, user aware
Optimize user interface
LBNL
User sensing controls / occupancy and ambient light sensing
NEEA; various television manufacturers
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Optimize user interface. ilitate widespread adoption low power mode technology by developing optimized, intuitive, and tailored user interface and control capabilities.

Existing research: Lawrence Berkeley National Laboratory (LBNL).

- In December 2004, the Lawrence Berkeley National Laboratory (LBNL) developed Institute of Electrical and Electronics Engineers (IEEE) Standard #1621, "Standard for User Interface Elements in Power Control of Electronic Devices Employed in Office/Consumer Environments." The purpose of the standard is "to accomplish a similarity of experience of power controls across all electronic devices so that users will find them easier to use and be more likely to utilize power management features that save energy" (http://eetd.lbl.gov/Controls/1621/).
- LBNL has also developed the Institute of Electrical and Electronics Engineers (IEEE) Standard #1621, "Standard for User Interface Elements in Power Control of Electronic Devices Employed in Office/Consumer Environments" (http://eetd.lbl.gov/Controls/1621/). There is still much research needed in this area

Key research questions:

1. What interface cues do people respond to?
2. What display standards should be consistent from device to device?
3. What metric should be used to report energy use?
4. What is relationship to monitoring, control, and communication characteristics?
5. What user interface standards should be developed or updated—power control, occupancy, scheduling, pricing, lighting, HVAC?

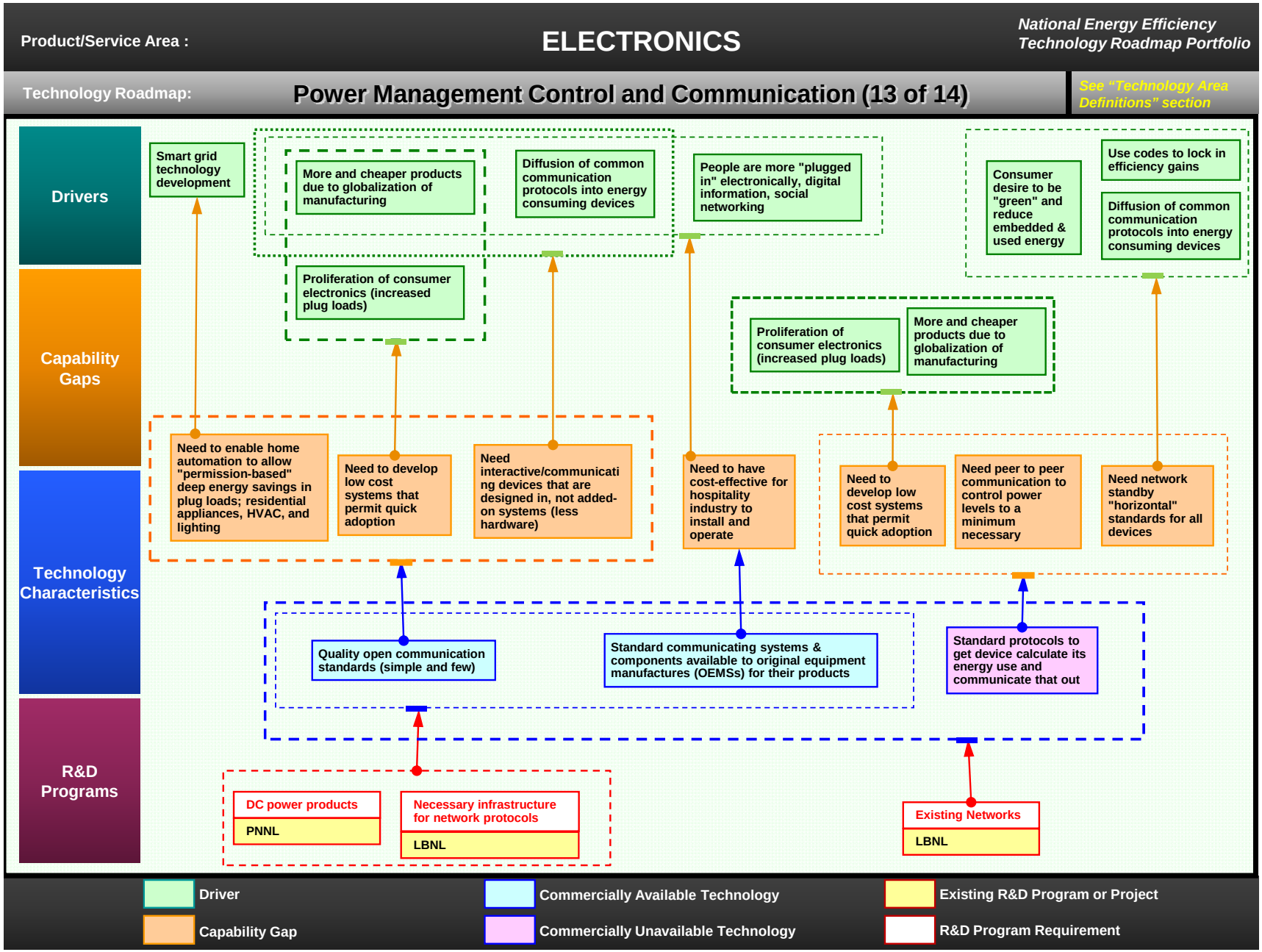
User sensing controls/occupancy and ambient light sensing. Stakeholders indicate that research in this area is underway at a variety of television manufactures, but R&D is not accessible for collaboration. To facilitate widespread adoption of sleep mode technology, study the way the most common user groups use electronic devices so the sleep mode technology will be compatible with their behavior and not cause user inconveniences.

Existing research: Various television manufactures, Northwest Energy Efficiency Alliance (NEEA).

- NEEA's "Energy Forward NW" initiative: http://energyefficientelectronics.org/news/.
- *[Summaries of existing research pending]*

Key research questions:

1. How to asses occupancy or usage? What sensors and measurements can help decide what power mode devices should be in?
2. Are required sensors mature? Or is more development required?
3. How can occupancy and light information be communicated to the network?


Product/Service Area :
ELECTRONICS
National Energy Efficiency Technology Roadmap Portfolio
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Power Management Control and Communication (13 of 14)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Smart grid technology development
More and cheaper products due to globalization of manufacturing
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People are more "plugged in" electronically, digital information, social networking
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Need to develop low cost systems that permit quick adoption
Need peer to peer communication to control power levels to a minimum necessary
Need network standby "horizontal" standards for all devices
Quality open communication standards (simple and few)
Standard communicating systems & components available to original equipment manufactures (OEMSs) for their products
Standard protocols to get device calculate its energy use and communicate that out
DC power products
PNNL
Necessary infrastructure for network protocols
LBNL
Existing Networks
LBNL
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

DC power products. How can DC powering reduce energy use in small devices?

Existing research: Pacific Northwest National Laboratory (PNNL).

- *[Summaries of existing research pending]*

Key research questions:

1. What standard DC power technologies exist? What are relevant efficiencies of DC supplies or when source is AC or DC supply
2. What is measured energy use of DC devices vs. AC counterparts?
3. Where is DC a good solution for energy or other purposes?
4. What updates to DC power technologies would be helpful?

Necessary infrastructure for network protocols. Establish basic semantic descriptions of real world information so it can be represented in network protocols. Examples include device taxonomy (perhaps several), location, occupancy/presence, pricing, scheduling.

Existing research: Lawrence Berkeley National Laboratory (LBNL) .

- *[Summaries of existing research pending]*

Key research questions:

1. What existing standards or concepts are relevant?
2. What standards org. should host end result?
3. What process should be done to provide results?

Existing Networks. Hardware presented in buildings today—network equipment and devices connected to networks—can provide information useful for energy purposes. Examples include status, occupancy, temperature, etc. This data is rarely utilized. Explore what could be gleaned from existing hardware and demonstrate how to do it. Includes data delivered to other devices as well as to people.

Existing research: Lawrence Berkeley National Laboratory (LBNL) .

- *[Summaries of existing research pending]*

Key research questions:

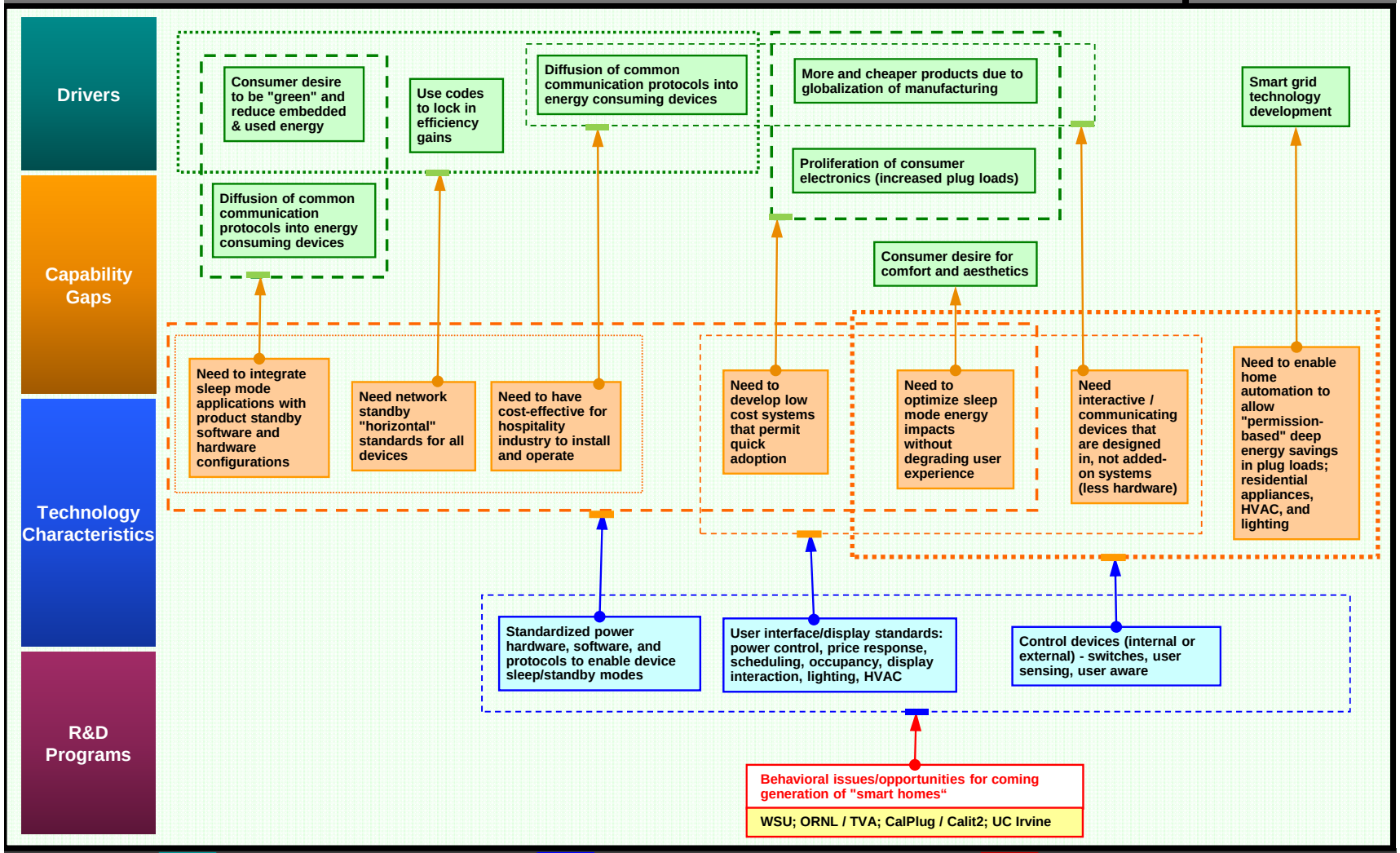
1. What information is or could be available?
2. What could small additional investments bring (e.g. USB temp-sensor or wireless access point)?
3. How do we get info out to be useful?
4. How could software / firmware upgrades make this work even better?

Product/Service Area : **ELECTRONICS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Power Management Control and Communication (14 of 14)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Behavioral issues/opportunities for coming generation of "smart homes. Perform human factors R&D to develop understanding of opportunities and barriers for energy reductions in home automation using current and emerging technologies.

Existing research: Washington State University (WSU); Oak Ridge National Laboratory (ORNL) with Tennessee Valley Authority (TVA); California Plug Load Research Center (CalPlug) with California Institute for Telecommunications and Information Technology (CALIT2), University of California Irvine.

- CalPlug:http://calplug.uci.edu/.
- CALIT2: http://www.calit2.net/.

- *[Summaries of existing research pending]*

Key research questions:

1. What are consumer/customer/homeowner motivations?
2. What are the biggest barriers to energy savings using home energy management systems?

Heating, Ventilation, and Air Conditioning (HVAC) Roadmaps

This section contains the following roadmaps:

- Commercial and Residential Water Heating
- Fault Detection, Predictive Maintenance, and Controls
- Heat Recovery and Economizer Optimization
- Heating & Cooling Production and Delivery
- HVAC Motor-driven Systems
- Commercial Integrated Buildings
- Residential HVAC
- Modeling, Lab and Field Testing

Other relevant sources:

The list below is intended to be broadly representative rather than exhaustive and will be updated as new information becomes available.

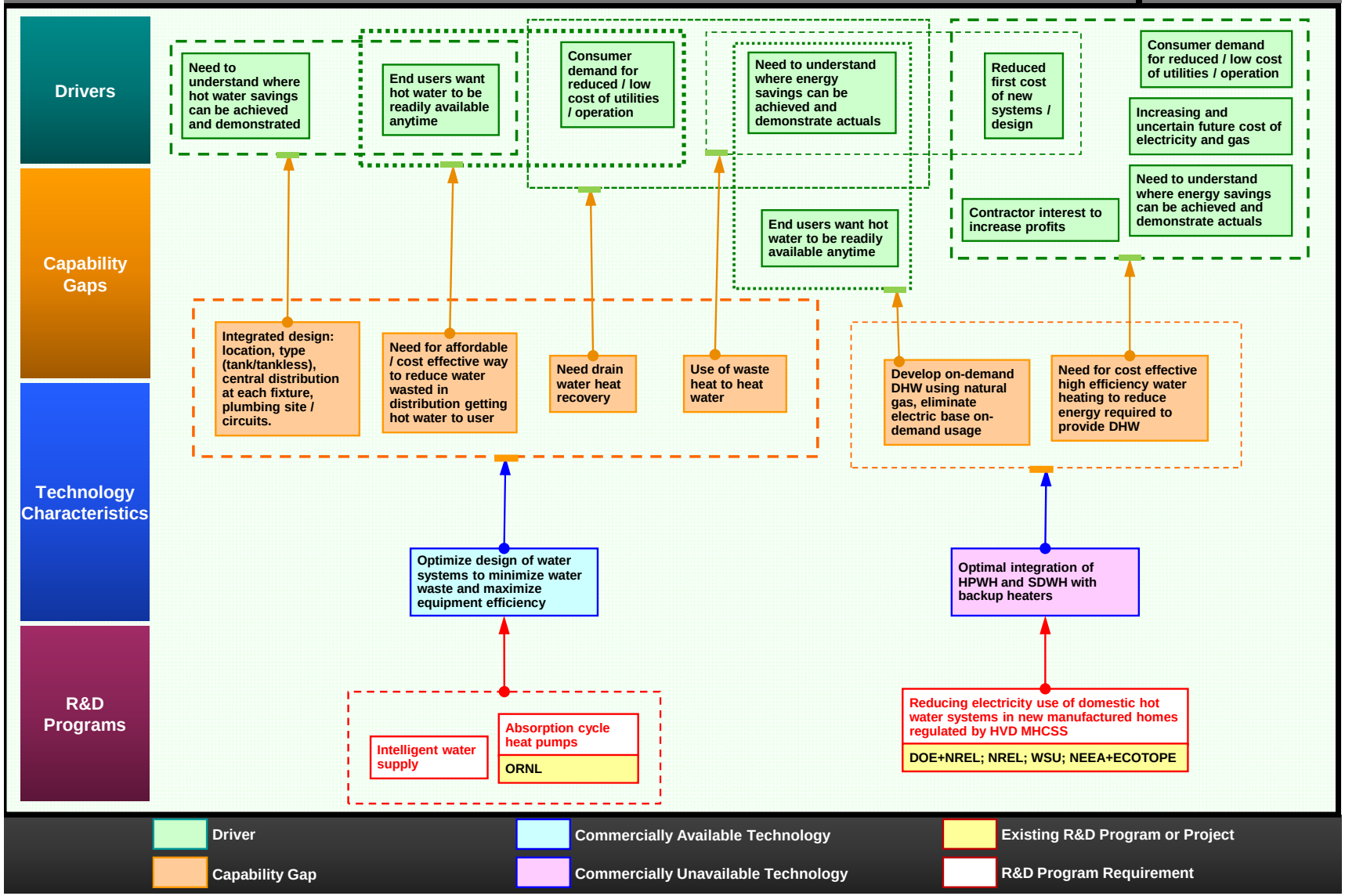
Oak Ridge National Laboratory, *Research and Development Roadmap for Water Heating Technologies*, prepared by Navigant Consulting, Inc., Sep. 30, 2011, http://www.ornl.gov/ci/ees/etsd/btric/pdfs/WaterHeatingTechnologiesRoadmap_9-30-2011_FINAL.pdf.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Commercial and Residential Water Heating (1 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

General note on water heating: The American Council for an Energy-Efficient Economy published a report in late 2011 on emerging water heating technologies; see Harvey Sachs, Jacob Talbot, Nate Kaufman, "Emerging Hot Water Technologies and Practices for Energy Efficiency as of 2011," ACEEE Report Number A112, Oct. 2011 (rev. Feb. 2012), http://www.aceee.org/research-report/a112.

Reducing electricity use of domestic hot water systems in new manufactured homes regulated by HUD MHCSS. Most U.S. Housing and Urban Development (HUD) standards for manufactured homes (Manufactured Home Construction and Safety Standards, MHCSS) use electric resistance tanks to heat domestic hot water (DHW). Currently customer cannot purchase solar DHW, heat pump water heater (HPWH) on other emerging technologies (ETs) as standard on options. No HUD-approved design exists. Most HVD-code home are sited in warm sunny climates where this ET's work great.

Existing research: Subject matter experts referred to HPWH research at the U.S. Department of Energy (DOE) with National Renewable Energy Laboratory (NREL); solar domestic hot water (SDHW) research at NREL; solar ready/HPWH research at Washington State University (WSU); and HPWH research by the Northwest Energy Efficiency Alliance (NEEA) and Ecotope.

- *[Summaries of existing research pending]*

Key research questions:

1. Investigate cost / benefit of SDHW solar ready, HPWH, plumbing design, etc.
2. How does cost / benefit change if ET is a standard practice?
3. What are the geographical issues that impact ET designs? Wind speed, solar installation, etc.
4. What specifications are needed for: solar ready SDHW, HPWH installation?
5. what noise fixture demand issues that may decrease performance over its useful life?

Absorption cycle heat pumps. Research cost effective ways to apply absorption cycle heat pumps to heat water.

Existing research: Oak Ridge National Laboratory (ORNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Can miniaturization of absorption technology reduce cost and still provide sufficient water delivery?
2. Identify potentially beneficial low temperature heat sources to drive cycle.

Intelligent water supply. Research to minimize water waste and provide hot water when needed, provide a solution that will learn usage patterns to meet consumer needs and adjust as needed, while allowing for manual demand.

Existing research: None identified.

Key research questions:

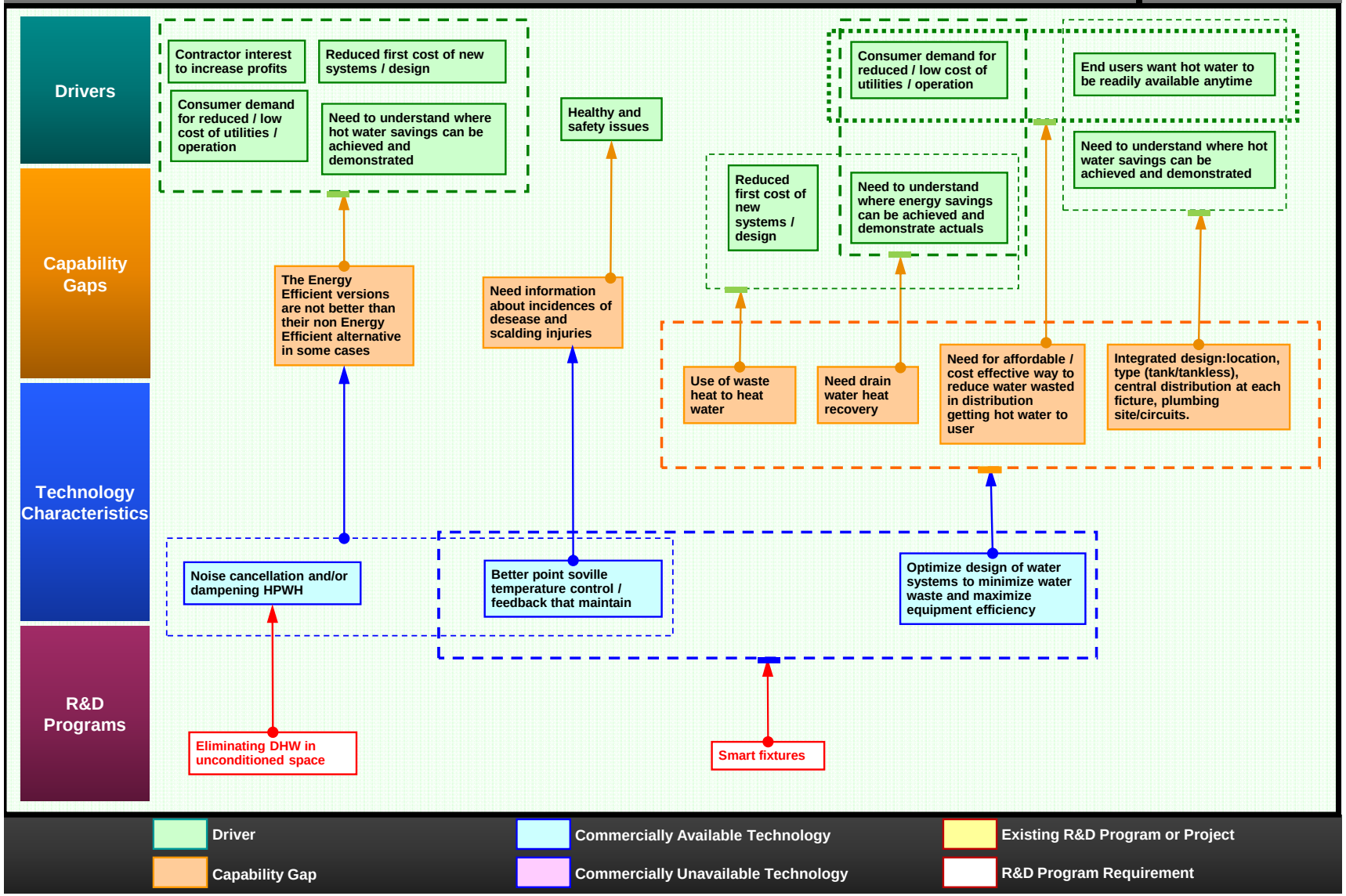
1. What are typical usage patterns for DHW? Is hot water available when needed?
2. How much water is wasted before hot water is seen at POU?
3. Embedded energy of wasted water?
4. Can technology (sensors, controls, pumps) be integrated cost effectively to minimize waste, provide hot water when needed and reduce energy waste?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Commercial and Residential Water Heating (2 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Smart fixtures. Research methods to integrate temperature control, water use feedback, etc into showers faucets and other end uses of hot water.

Existing research: None identified.

Key research questions:

1. What cold/hot water controls can cost effectively maintain constant water temperature at the fixture?
2. How can smart fixtures be powered?
3. How much energy/water is saved when use feedback is delivered at the fixture?

Eliminating DHW in unconditioned space. This effort via 1 code on programs will reduce wasted electricity from tank, pipes, etc. It also reduces cost from freeze protection, insurance claims, etc.

Existing research: None identified.

Key research questions:

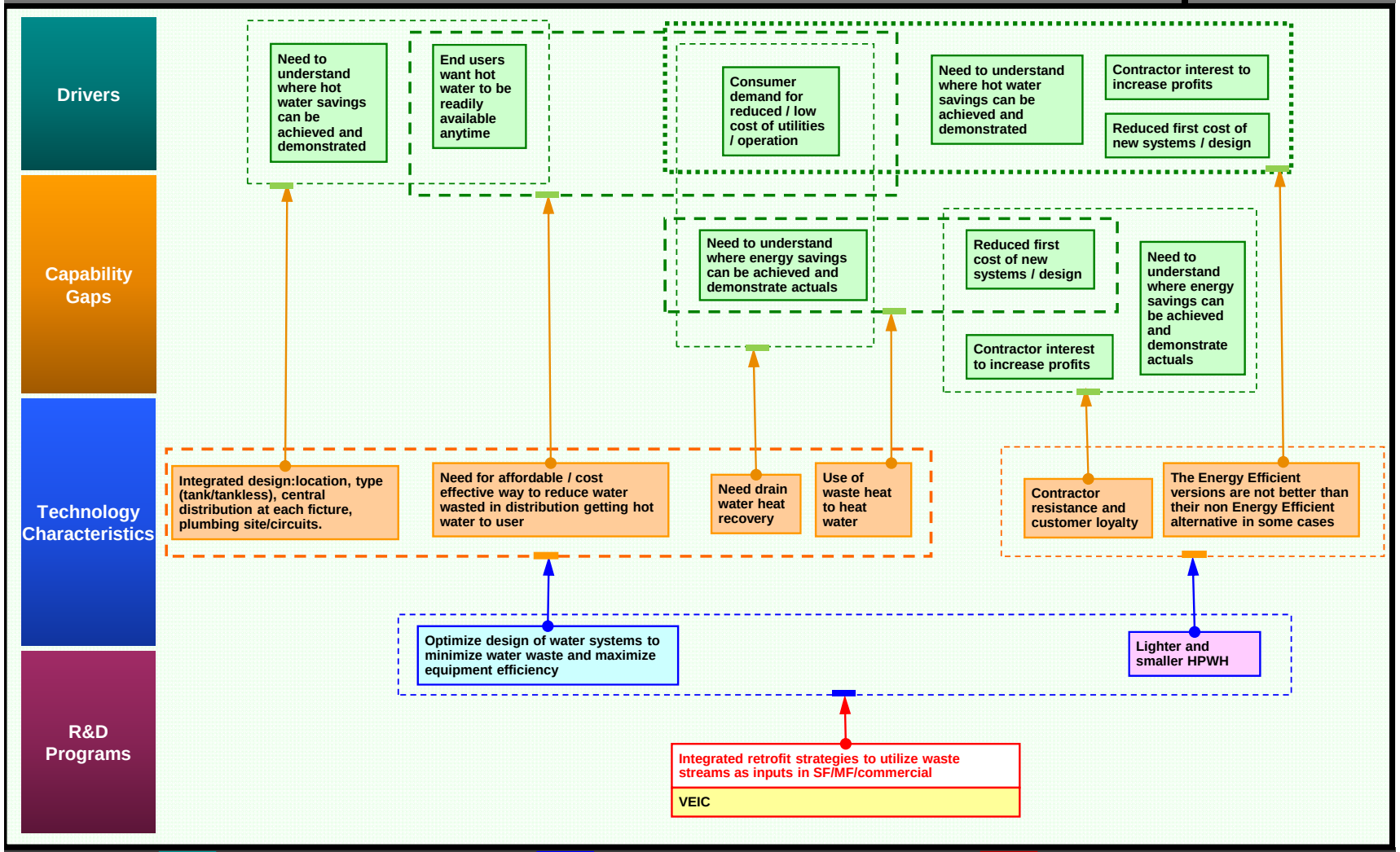
1. Evaluate cost / benefit of moving to conditioned space from attic, garage, new space to home.
2. What are the cost impacts?
3. What is the energy savings?
4. What are the benefits in terms of freeze protection?
5. What are the water savings benefits from shorter pipe?
6. What specifications are needed in programs and codes?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Commercial and Residential Water Heating (3 of 8)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

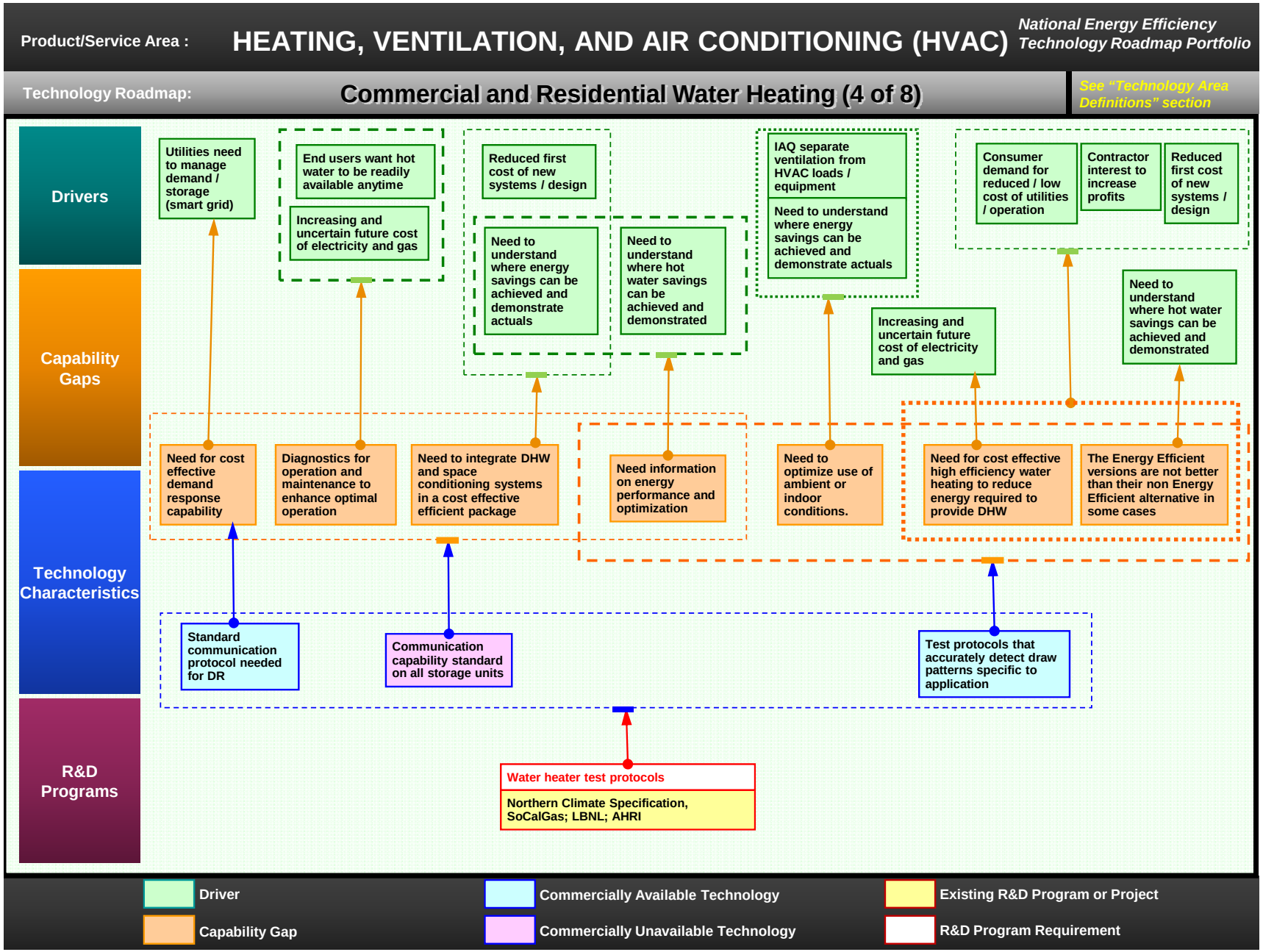
Integrated retrofit strategies to utilize waste streams as inputs in SF/MF/commercial. Waste heat from appliances/HVAC/clothes washing/bathrooms/drains being utilized (or cool air from heat pump water heater (HPWH)) in various ways including but not limited to co-location/ducting/equipment integration in single family (SF), multi-family (MF), and commercial buildings.

Existing research: Vermont Energy Investment Corporation (VEIC).

- *[Summaries of existing research pending]*

Key research questions:

1. Implications of ducting moist air or dryer vent air to utility closets and basements.
2. Can plumbing be cost-effectively redesigned to minimize runs?
3. Benefits/tradeoffs of venting dry, cool air to crawl spaces/attics.
4. How can all the variants pieces of equipments be connected?
5. Consider use of water heaters for air conditioning in laundries or restaurants.


Product/Service Area :
HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Commercial and Residential Water Heating (4 of 8)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Utilities need to manage demand / storage (smart grid)
End users want hot water to be readily available anytime
Increasing and uncertain future cost of electricity and gas
Reduced first cost of new systems / design
Need to understand where energy savings can be achieved and demonstrate actuals
Need to understand where hot water savings can be achieved and demonstrated
IAQ separate ventilation from HVAC loads / equipment
Need to understand where energy savings can be achieved and demonstrate actuals
Consumer demand for reduced / low cost of utilities / operation
Contractor interest to increase profits
Reduced first cost of new systems / design
Increasing and uncertain future cost of electricity and gas
Need to understand where hot water savings can be achieved and demonstrated
Need for cost effective demand response capability
Diagnostics for operation and maintenance to enhance optimal operation
Need to integrate DHW and space conditioning systems in a cost effective efficient package
Need information on energy performance and optimization
Need to optimize use of ambient or indoor conditions.
Need for cost effective high efficiency water heating to reduce energy required to provide DHW
The Energy Efficient versions are not better than their non Energy Efficient alternative in some cases
Standard communication protocol needed for DR
Communication capability standard on all storage units
Test protocols that accurately detect draw patterns specific to application
Water heater test protocols
Northern Climate Specification, SoCalGas; LBNL; AHRI
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Water heater test protocols. Revise existing water heater testing protocols to accurately predict the way hot water is used.

Existing research: Northern Climate Specification, Southern California Gas Company (SoCalGas).

- *[Summaries of existing research pending]*

Key research questions:

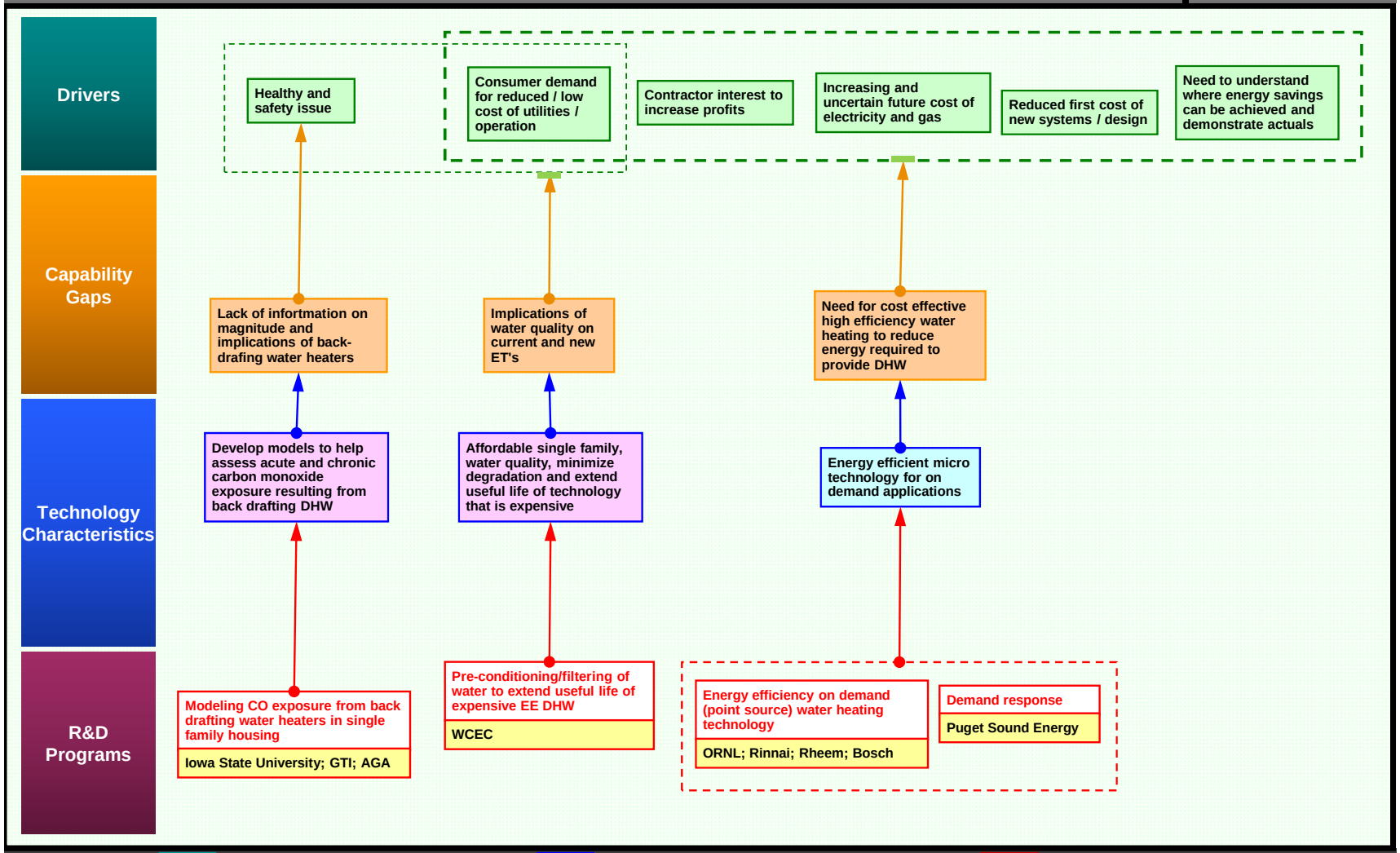
1. What are water draw patterns in a single family homes. multi family, or commercial.
2. Are technology specific test protocols necessary?
3. Establish protocols based on equipment utilization, include climate specific.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Commercial and Residential Water Heating (5 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Modeling CO exposure from back drafting water heaters in single family housing.

Building Performance Institute (BPI), U.S. Department of Energy (DOE), and other residential retrofit programs have devoted significant resources to determine the potential for back drafting of carbon monoxide (CO) from domestic hot water (DHW) tanks as a result of weather activities on existing systems.

Existing research: Iowa State University, Gas Technology Institute (GTI), AGA.

- *[Summaries of existing research pending]*

Key research questions:

1. Combine CONTAM airflow and contaminant transport analysis program with SIMVENT ventilation simulator to allow for the assessment of interactions between five gases and other building systems.
2. Run simulation to help assess carbon monoxide exposure to occupants acute or chronic.
3. Develop research plan to validate model inputs assumption and model result.

Pre-conditioning/filtering of water to extend useful life of expensive EE DHW equipment.

In region with poor water quality, equipment must be replaced far more often, reducing willingness to invest in more expensive EE product. Pre-filtering/conditioning of water cost-effectively extend the performance life of expensive domestic hot water (DHW) equipment.

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC).

- Subject matter experts in September 2012 referenced work on water quality issues for evaporative cooling conducted by WCEC that could be applied here.

Key research questions:

1. Can we consider the multiple tanks as part of the cost effectiveness calculations?
2. Does pre conditioning measurably extend DHW tank's life?
3. Are there measurable non-energy benefits (NEBs)?
4. Can DHW spaces generally accommodate a pre-conditioner?
5. Can DHW be integrated at the factory to precondition?
6. Does energy used by pre-conditioner mitigate the potential energy saved by the HPWH?

Continued . . .

Demand response. Research communication and control methods to facilitate demand response on new water heaters.

Existing research: Puget Sound Energy.

- *[Summaries of existing research pending]*

Key research questions:

1. Which utility device communication protocols would best lead to a standard?
2. What is the incremental costs of adding demand response (DR) capability to new efficient water heaters?

Energy efficiency on demand (point source) water heating technology. Research alternatives to electric resistance on demand water heating that have energy factor greater than two.

Existing research: Oak Ridge National Laboratory (ORNL), Rinnai, Rheem, Bosch.

- *[Summaries of existing research pending]*

Key research questions:

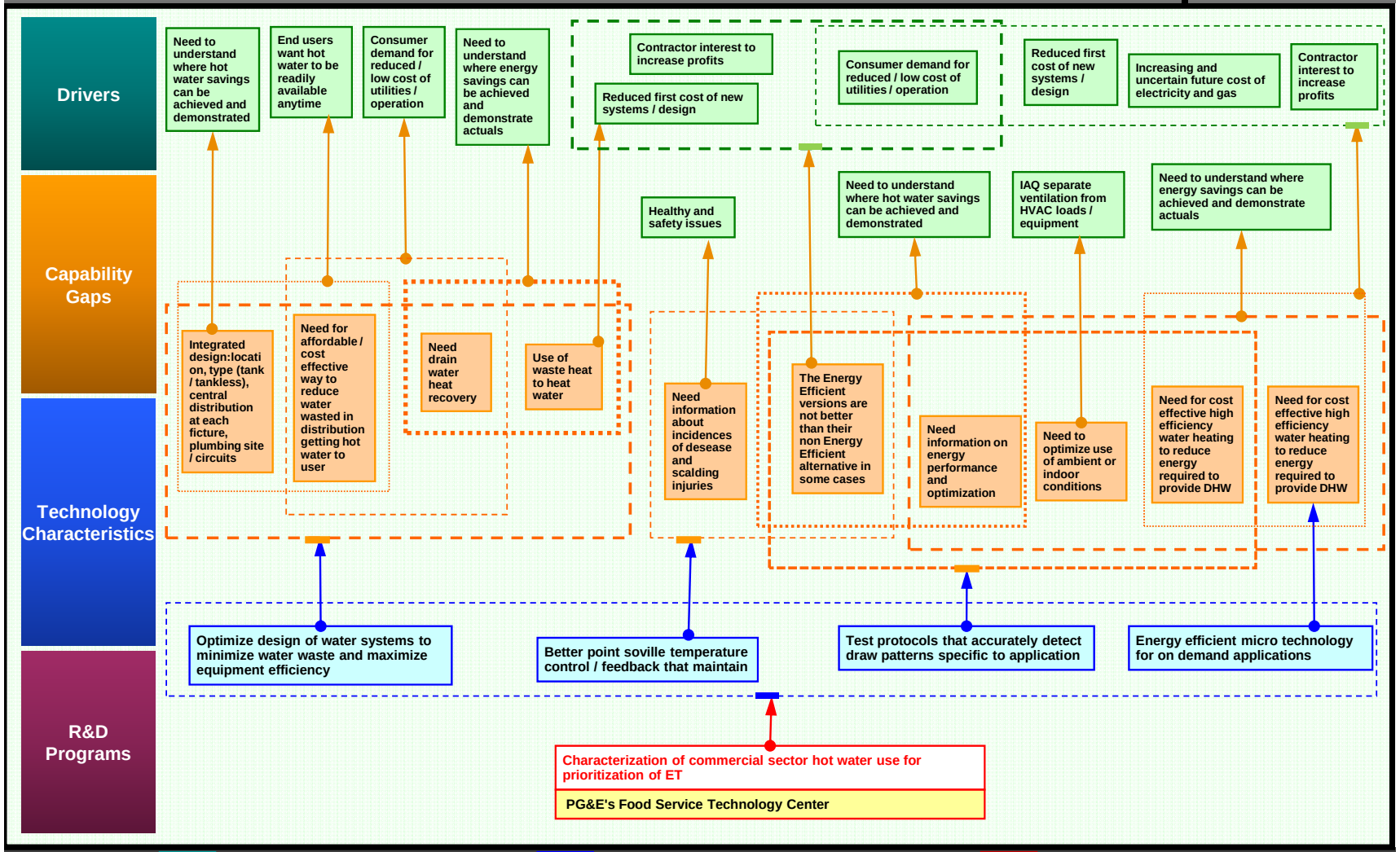
1. What micro heat pump technologies could be used for on demand water heating?
2. Are there nano technologies out there that could serve this purpose?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Commercial and Residential Water Heating (6 of 8)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

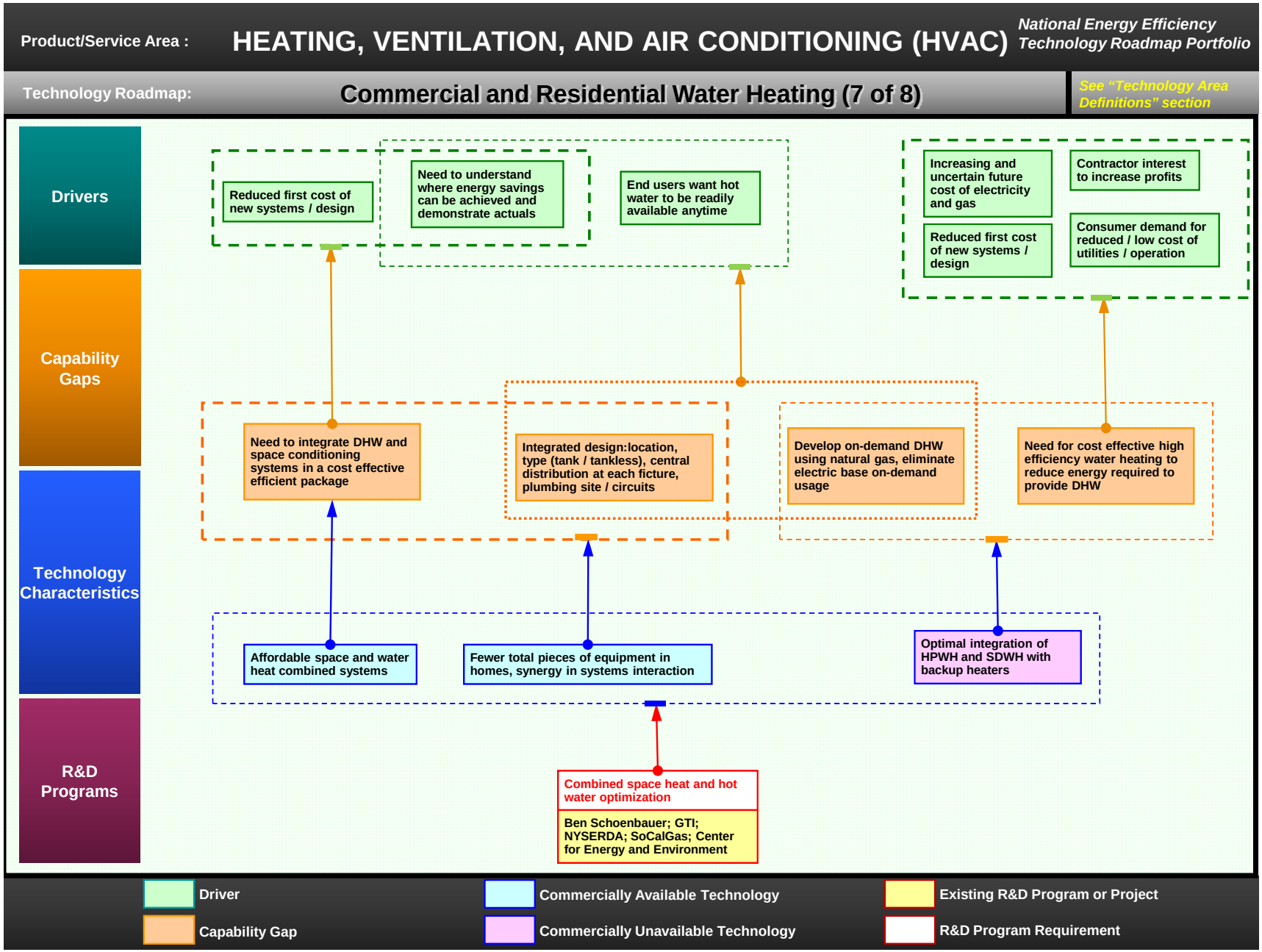
R&D Program Summaries

Characterization of commercial sector hot water use for prioritization of ET. The more hot water used the better the cost / benefit for emerging technologies (ETs) that recover waste heat.

Existing research: Pacific Gas & Electric (PG&E) Food Service Technology Center has looked at hot water use in commercial kitchens.

Key research questions:

1. Review current assumption of fixture hot water demand.
2. Rank those sectors which the highest usage.
3. Evaluate cost / benefit of emerging technologies in those sector using simulation models.
4. Conduct parametric analysis of key variables that have the greatest impact on cost / benefit.
5. Develop research plan to validate models.


Product/Service Area :
HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Commercial and Residential Water Heating (7 of 8)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Reduced first cost of new systems / design
Need to understand where energy savings can be achieved and demonstrate actuals
End users want hot water to be readily available anytime
Increasing and uncertain future cost of electricity and gas
Contractor interest to increase profits
Reduced first cost of new systems / design
Consumer demand for reduced / low cost of utilities / operation
Need to integrate DHW and space conditioning systems in a cost effective efficient package
Integrated design:location, type (tank / tankless), central distribution at each ficture, plumbing site / circuits
Develop on-demand DHW using natural gas, eliminate electric base on-demand usage
Need for cost effective high efficiency water heating to reduce energy required to provide DHW
Affordable space and water heat combined systems
Fewer total pieces of equipment in homes, synergy in systems interaction
Optimal integration of HPWH and SDWH with backup heaters
Combined space heat and hot water optimization
Ben Schoenbauer; GTI; NYSERDA; SoCalGas; Center for Energy and Environment
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Combined space heat and hot water optimization. Develop installation and commissions guidelines for heat and DHW combined systems.

Existing research: Ben Schoenbauer, Gas Technology Institute (GTI), New York State Energy Research and Development Authority (NYSERDA), Southern California Gas Company (SoCalGas), Center for Energy and Environment (CEE).

- CEE: http://www.mncee.org/.
- *[Summaries of existing research pending]*

Key research questions:

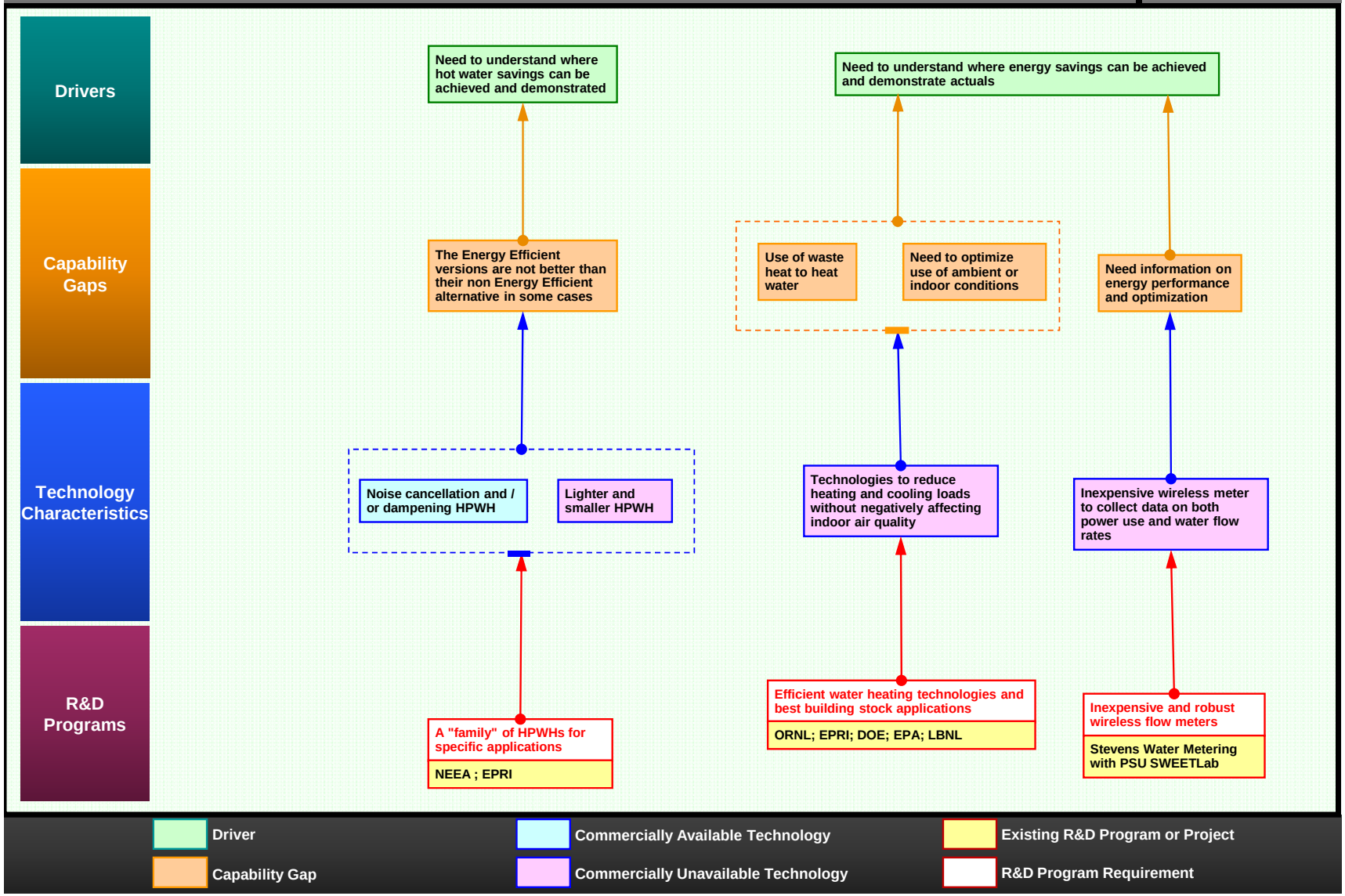
1. Establish optimal return water temperature.
2. Identify air handler size and optimal cubic feet per minute (CFM) fan flow.
3. Establish guidelines for equipment choice based on water quality (hardness)—tank less not suited for hard water.
4. Identify training criteria for contractor base.
5. Identify key elements to reduce equipment and installed costs.
6. Identify optimal piping configurations.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Commercial and Residential Water Heating (8 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Efficient water heating technologies and best building stock applications. Evaluate efficiency of: 1) compressors based water heating 2) solar water heating 3) heat recovery water heating, and then define the characteristics of building stock each technology is optimally suited to.

Existing research: Oak Ridge National Laboratory (ORNL), Electric Power Research Institute (EPRI), U.S. Department of Energy (DOE), U.S. Environmental Protection Agency (EPA).

- For ORNL's work in this area, see Appendix B.
- For EPA's WaterSense program, see http://www.epa.gov/watersense/.
- *[Summaries of existing research pending]*

Key research questions:

1. Define barriers of each technology in terms of building stock applicability.
2. Define drivers to lower equipment installation and commissioning cost of each technology.
3. Define best practices for optimizing efficiencies of each technology and building type.
4. Define building characteristics for optimizing each technology.
5. Measured data, not just modeled three years ideally.

A "family" of HPWHs for specific applications. Today's heat pump water heaters (HPWHs) are for the most part one size fits all, similar to electric resistance water (for residential application). The future HPWHs need to be tailored for specific applications including location, requirement draw and connect ability leg (e.g., solar water heat)..

Existing research: Northwest Energy Efficiency Alliance (NEEA), Electric Power Research Institute (EPRI).

- For EPRI's work in this area, see Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. What technologies can be integrated into a HPWH to reduce noise, to vary the size/footprint/geometry?
2. What technologies can be offered for optimal installation in conditional or unconditional spaces?
3. What technologies can be offered to best integrate a HPWH with a home or commercial building HVAC system?
4. What kind of control technologies can be offered on the tank—one home energy management (HEM)? For specific application?
5. Where can we improve performance?

Inexpensive and robust wireless flow meters. (Summary not yet provided).

Existing research: Stevens Water Metering with Portland State University SWEETLab (http://www.sweetlab.org/) .

Key research questions:

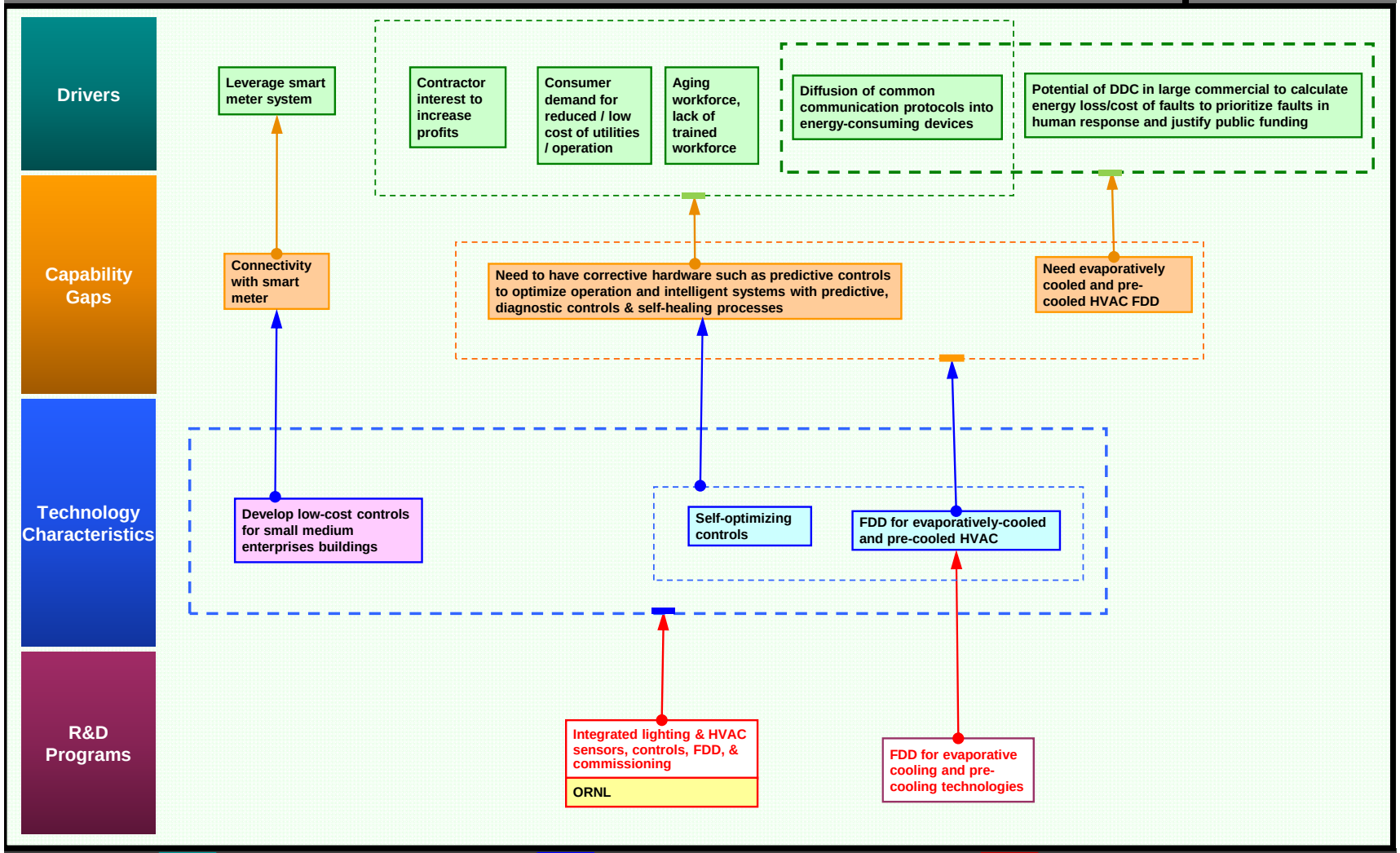
1. Questions not yet specified.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (1 of 13)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

FDD for evaporative cooling and pre-cooling technologies. Fault detection and diagnosis (FDD) approaches to identify the faults that typically occur in evaporation cooling and pre-cooling technologies, develop algorithms, develop prototype tools, field and lab test tools.

Existing research: None identified.

Key research questions:

1. Literature search into faults and technologies.
2. Identify faults and available sensors.
3. Develop algorithms.
4. Develop prototype tools.
5. lab and field test.

Integrated lighting and HVAC sensors, controls, FDD, and commissioning. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL).

- ORNL: See Appendix B.

Key research questions:

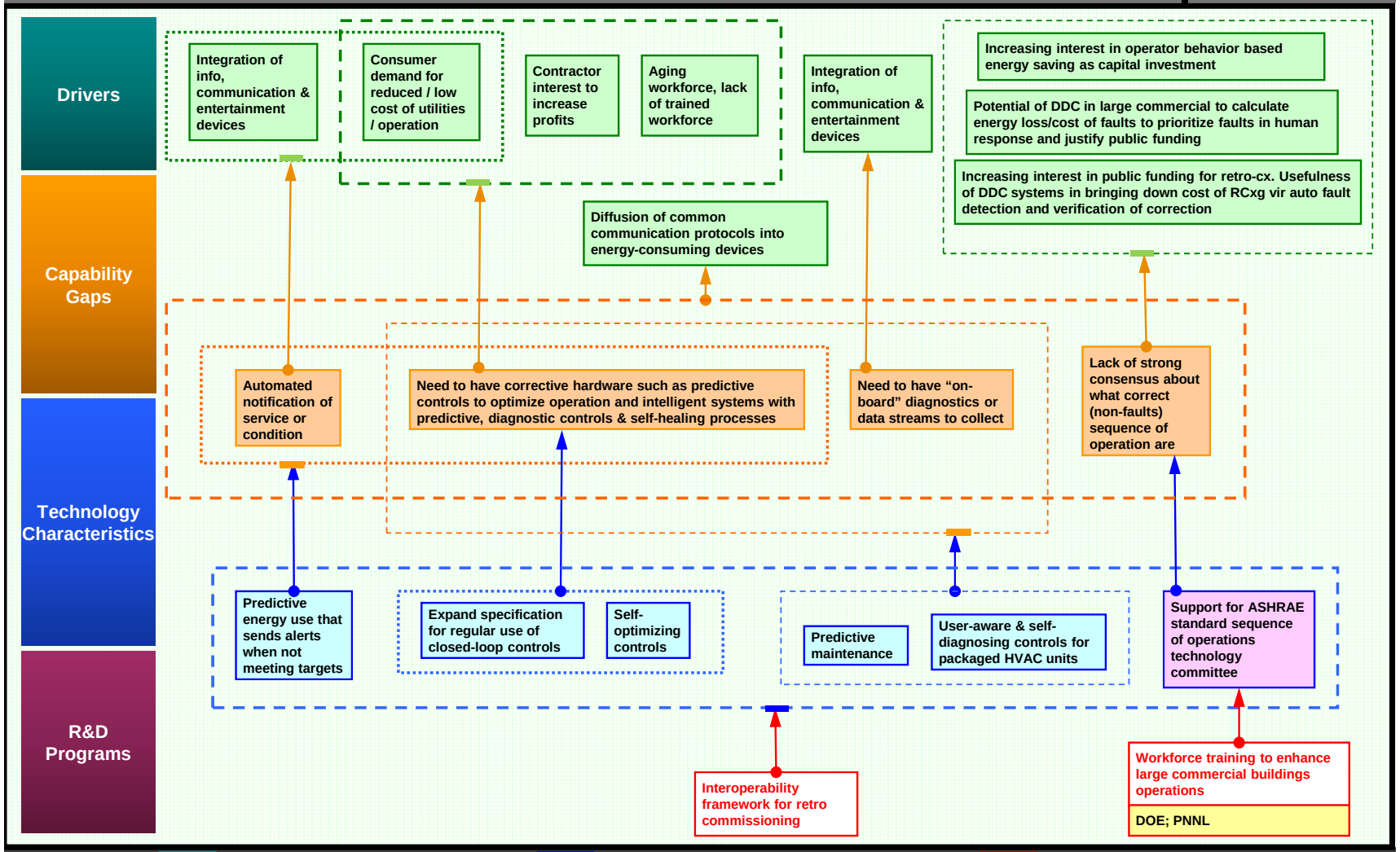
1. Questions not yet specified.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (2 of 13)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Workforce training to enhance large commercial buildings operations. Currently buildings are operated inefficiently; they don't use all the capabilities of the building atomization systems.

Existing research: DOE/PNNL.

- *[Summaries of existing research pending]*

Key research questions:

1. How to improve workforce skills?

Interoperability framework for retro commissioning. Advanced sensors and controls for retro commissioning needs and intelligent interoperability framework to enable plug and play.

Existing research: None identified.

Key research questions:

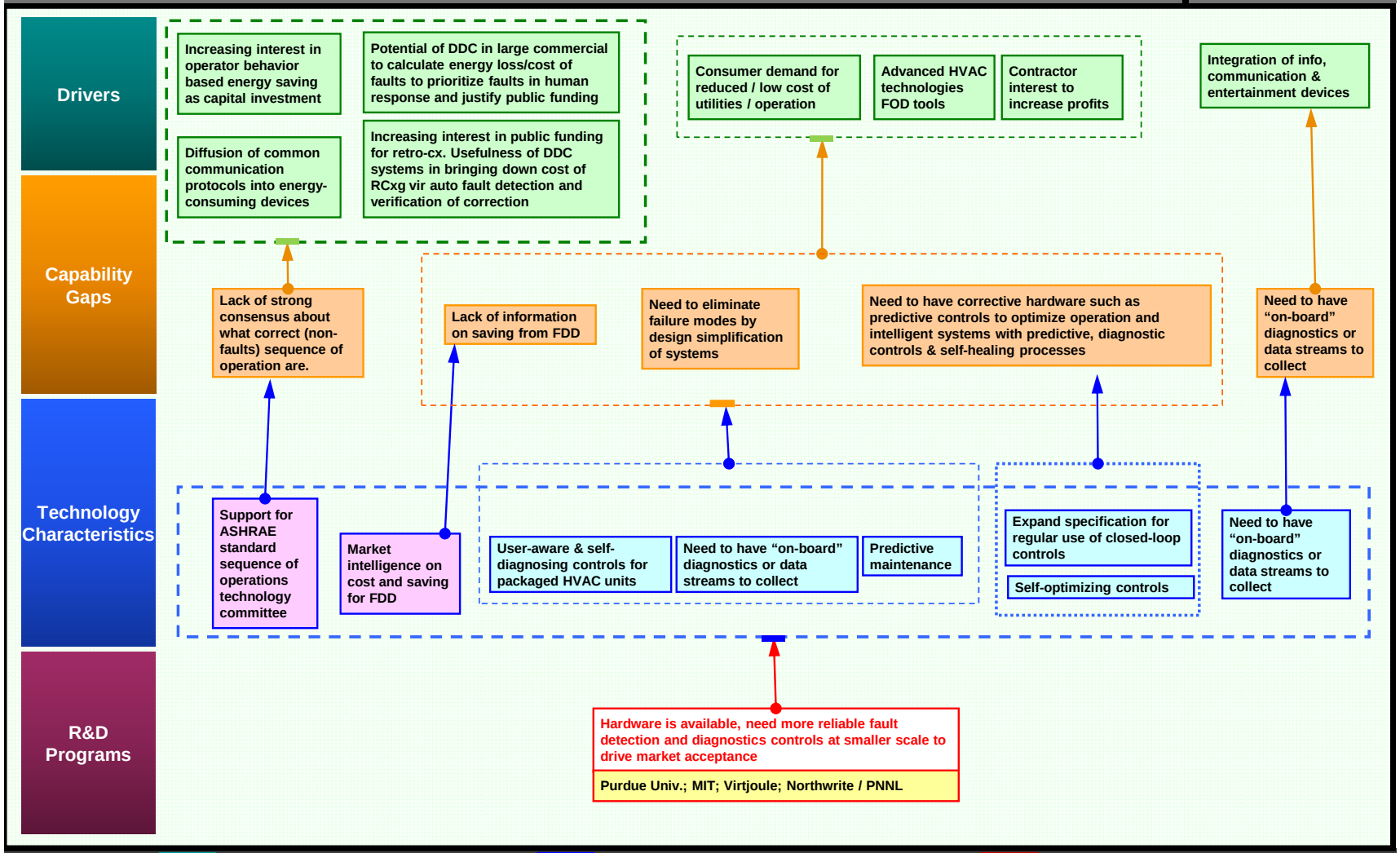
1. Develop light-weight middleware to enable plug and play of retro commissioning sensors.
2. Open standards-boned system.
3. Architectural definition.
4. What data specification for direct digital control (DDC) would help commissioning agents?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (3 of 13)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

Hardware is available, need more reliable fault detection and diagnostics controls at smaller scale to drive market acceptance. Much of the hardware useful for implementing self-diagnoses of HVAC equipment controls is available. The biggest remaining need is good software and design.

Existing research: Purdue University, Massachusetts Institute of Technology (MIT), Virtjoule, Northwrite & Pacific Northwest National Laboratory (PNNL).

- Engineering graduate student Siyu Wu is currently working on thesis research at the Applied Controls Laboratory of the University of California at Merced, under the guidance of Dr. Jian-Qiao Sun (http://faculty.ucmerced.edu/jqsun/index.html). They delivered a paper at the American Council for an Energy-Efficient Economy (ACEEE) 2010 conference, "Multilevel Fault Detection and Diagnosis on Office Building HVAC Systems." This paper presented a multilevel fault detection method that allowed for the uniform application of the FDD strategy to an entire building (http://eec.ucdavis.edu/ACEEE/2010/data/papers/1992.pdf).
- The Purdue University Energy Center's Smart Buildings Research group is working on fault detection and diagnostics software; as of Feb. 2012, specific R&D project information is not readily apparent through the research group's website, but general information can be found at http://www.purdue.edu/discoverypark/energy/research/efficiency/green_building.php.

Key research questions:

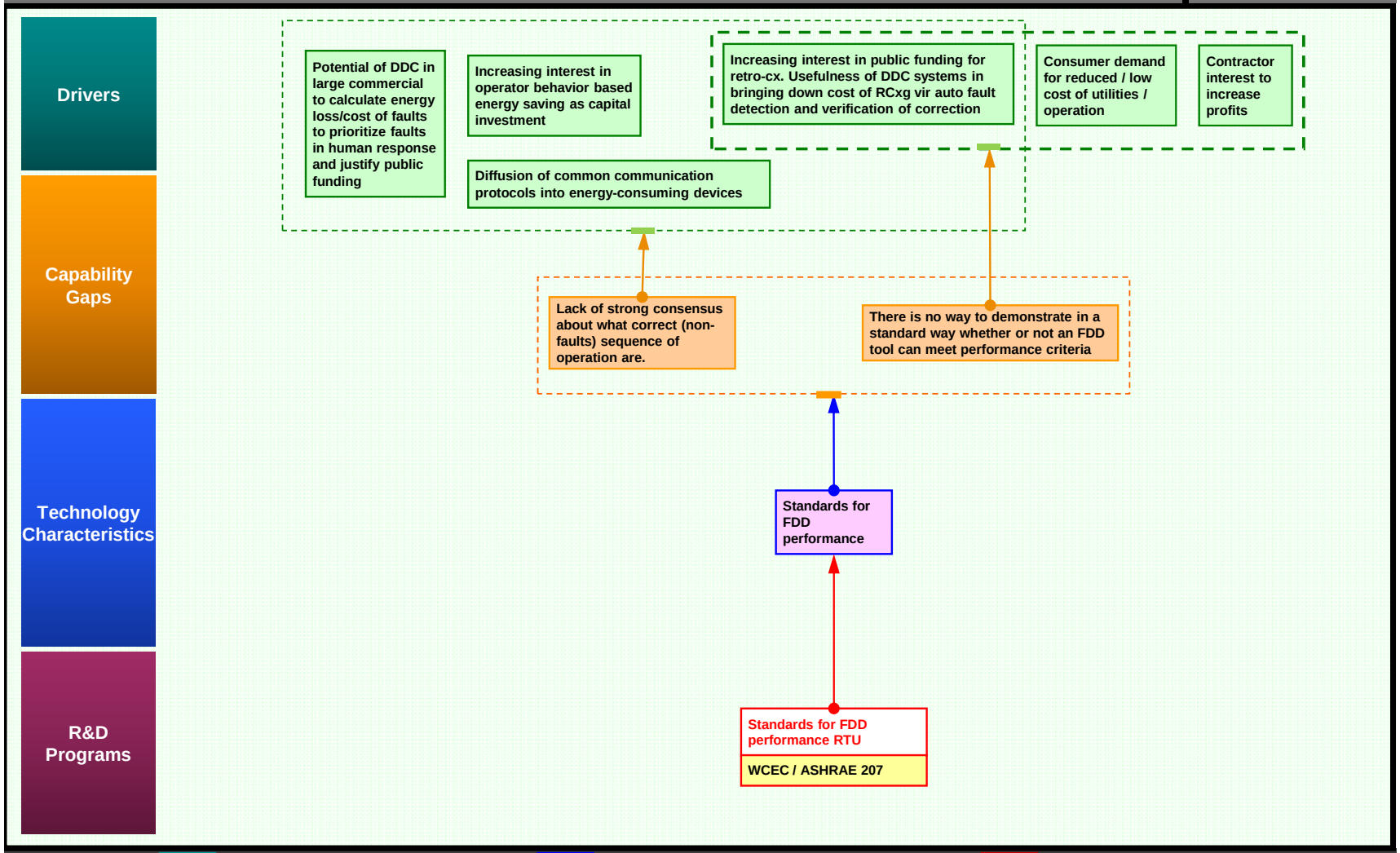
1. Questions not yet specified.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (4 of 13)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Standards for FDD performance RTU. Develop industry standards for testing of rooftop unite (RTU) fault detection and diagnosis (FDD) .

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC) / American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard Project Committee 207.

- *[Summaries of existing research pending]*

Key research questions:

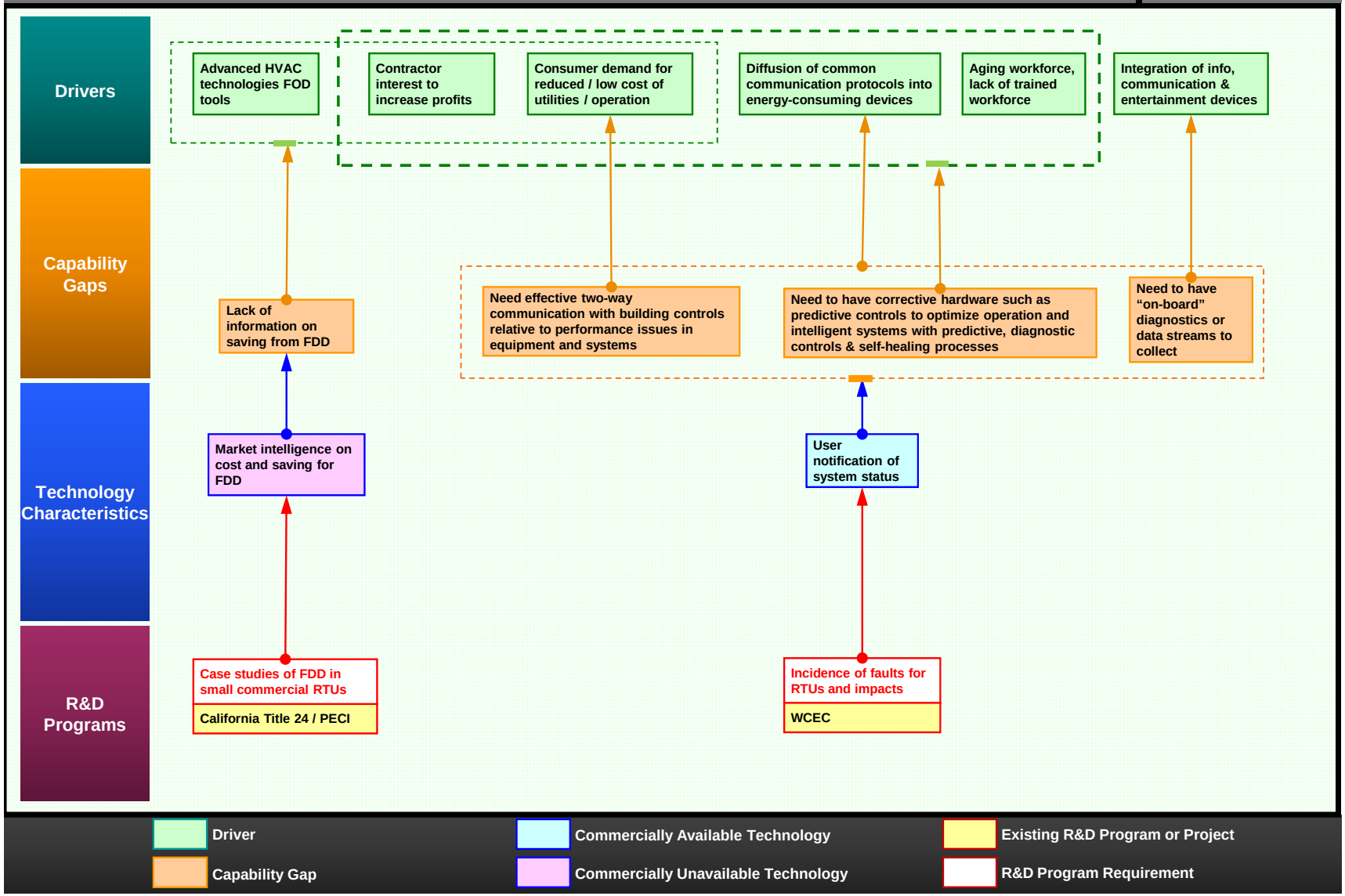
1. Validate the standards that are developed for RTU performance testing.
2. Conduct lab test to identify the limits of applicability.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (5 of 13)**

See "Technology Area Definitions" section



R&D Program Summaries

Case studies of FDD in small commercial RTUs. Develop case studies of fault detection and diagnosis (FDD) implemented in rooftop units (RTUs). Also develop case studies of RTUs that did not have FDD.

Existing research: California Title 24 case / Portland Energy Conservation, Inc. (PECI).

- *[Summaries of existing research pending]*

Key research questions:

1. Identify case study sites, which have implemented FDD in certain sectors.
2. Try to find case studies that have measured data, document the successes, lesson learned, user satisfaction.
3. Find facilities that are willing to share problems they had, regardless of whether or not they have FDD.
4. Identify products that are available for FDD on RTUs

Incidence of faults for RTUs and impacts. Conduct a field study to examine the incidence of various faults occurring frequently in rooftop units (RTUs) and the impact of these faults.

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC).

- *[Summaries of existing research pending]*

Key research questions:

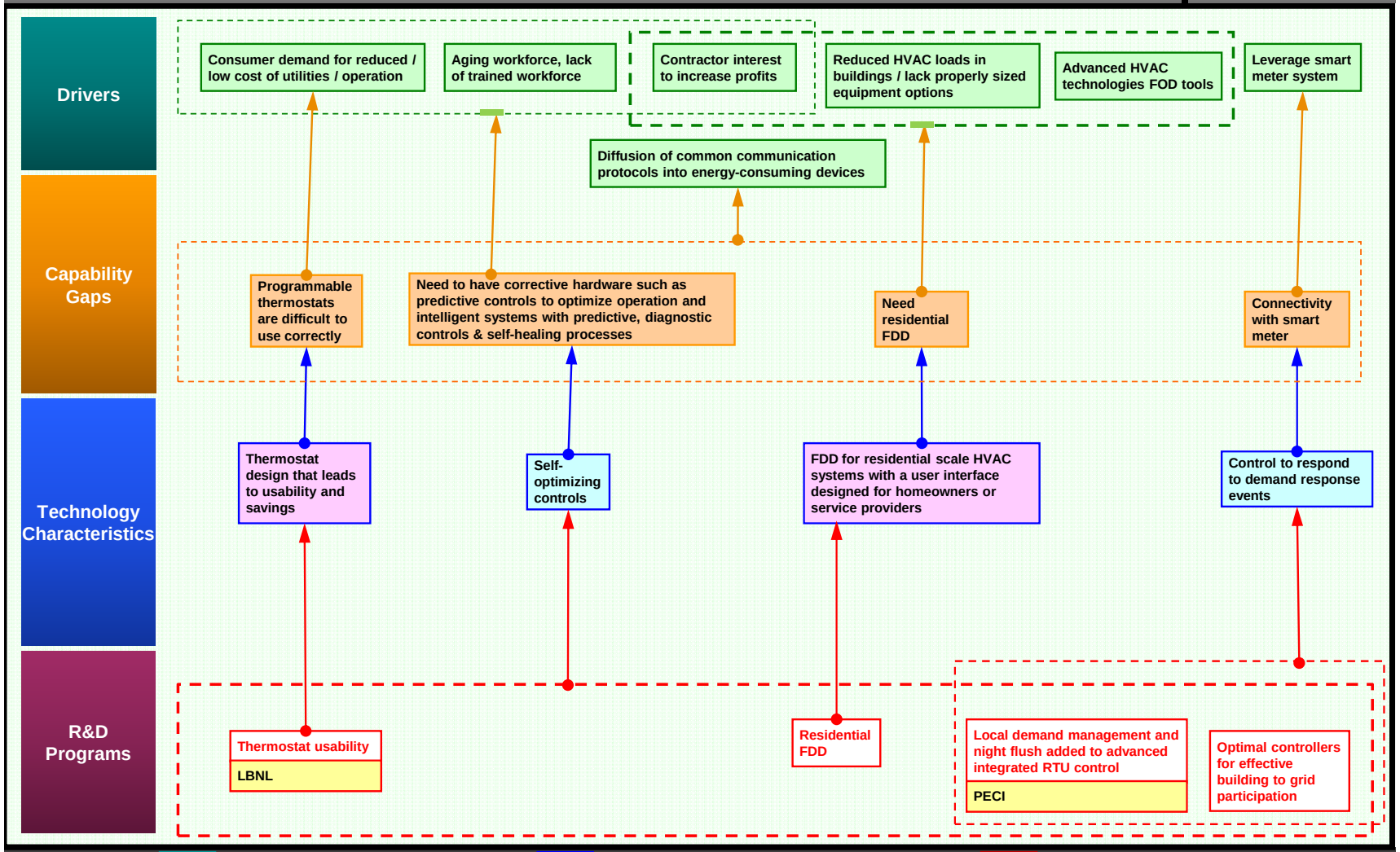
1. Develop a list of faults, clearly define and consistent with earlier studies.
2. Design a field study to identify the incidence of faults over time.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (6 of 13)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Thermostat usability. Investigate the usability of programmable thermostats and their real potential for savings in the field. Identify the potential for advanced thermostats.

Existing research: Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Develop metrics for the usability of thermostats.
2. Do usability studies with a wide range of demographics.
3. Characterize the advanced algorithms implemented in advanced thermostats.
4. Use modeling to identify the savings attributable to these advanced algorithms.
5. Do field studies of thermostat use.

Local demand management and night flush added to advanced integrated RTU control. Begin with premium ventilation controller and add night flush control on rooftop units (RTUs) and local demand management. Local demand management uses outside air as a trigger and can intersect with demand response communication.

Existing research: Portland Energy Conservation, Inc. (PECI).

- *[Summaries of existing research pending]*

Key research questions:

1. What is improved night flush sequence based on stimulation and savings:
   a. Thermal mass impact.
   b. Avoid morning heat.
2. Potential demand savings from set point reset based on OSA.
3. Demand and energy impact from field test.

Residential FDD. Development of fault detection and diagnosis (FDD) tools and algorithms suited to residential scale HVAC systems, with a user interface designed for homeowners or service providers.

Existing research: None identified.

Key research questions:

1. What faults typically occur in residential HVAC systems, negatively affecting energy efficiency?
2. How can these faults be detected cost effectively?
3. What are the UI requirements for residential occupants and for service contractors?

Optimal controllers for effective building to grid participation. Whole building optional controller driven by utility signals (bill, demand response (DR), peak) while maximizing benefit for building owner/tenant.

Existing research: None identified.

Key research questions:

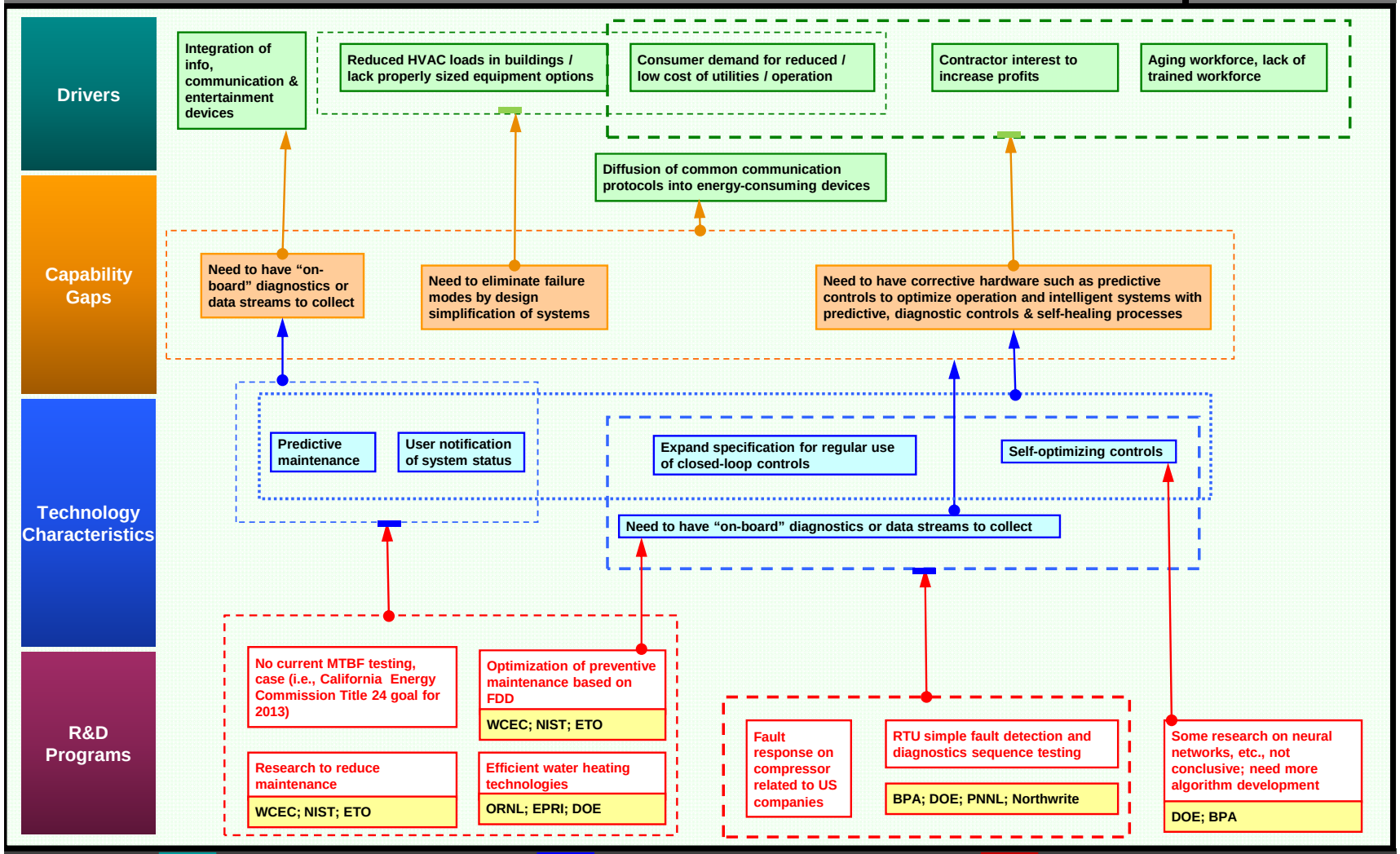
1. Design tool for controllers that are optimized for building-to-grid (B2G).
2. Complex interaction study for two-way stability consideration.
3. Open platforms for B2G controllers.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (7 of 13)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

RTU simple fault detection and diagnostics sequence testing. Bonneville Power Administration conducted research in 2008-2009 on roof-top units (RTUs) with special attention paid to controls and fault detection and diagnostics.

Existing research: Bonneville Power Administration (BPA), U.S. Department of Energy (DOE), Pacific Northwest National Laboratory (PNNL), Northwrite.

- BPA conducted research in 2008-2009 on roof-top units (RTUs) with special attention paid to controls and fault detection and diagnostics; see http://www.bpa.gov/energy/n/emerging_technology/AirHandlerControls. cfm.
- *[Summaries of other existing research pending]*

Key research questions:

1. Can simplified set up diagnostics speed and improve contractor setup of RTUs?
2. Will simplified fault detection and diagnosis (FDD) programming fit into memory of available custom controllers?
3. In a multiple building field deployment, what is energy savings based on pre/post monitoring?

Some research on neural networks, etc. not conclusive; need more algorithm development. More research on methods is needed to help inform design of self-healing, self-correction, and learning HVAC controls systems.

Existing research: DOE, BPA.

- *[Summaries of existing research pending]*

Key research questions:

1. How to make building operations more efficient?
2. How to automate detection/diagnostics and correction?

Efficient water heating technologies. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL), Electric Power Research Institute (EPRI), U.S. Department of Energy (DOE).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Fault response on compressor related to US companies. One of the important areas to develop right now is self-diagnostic controls. An important aspect of that is to develop and implement fault response on compressors.

Existing research: None identified.

Key research questions:

1. Integrate compressor self-diagnostic with RTU or split system diagnostics?
2. Identify interactions.
3. Develop prototype, test in lab and field.

Continued . . .

Optimization of preventive maintenance based on FDD. Apply fault detection and diagnosis (FDD) to reduce maintenance on energy efficient equipment to help expedite uptake of the equipment. Downtime in itself can be wasteful and reduces service. Replacing equipment prematurely likewise increases embedded energy of equipment and reduces service.

Existing research: Research is ongoing at the National Institute of Standards and Technology (NIST) and the Western Cooling Efficiency Center (WCEC) at the University of California Davis, and the Energy Trust of Oregon (ETO) is also involved in this work in some capacity.

- WCEC is working to commercialize fault detection and diagnostics tools. See Appendix B for more information.
- NIST's Energy and Environment Division has two ongoing fault detection and diagnostics projects. See Appendix B for more information.
- ETO staff reported in February 2012 that their projects and programs do not explicitly address maintenance reduction, though this is often an ancillary benefit of their work; they also do not work formally within a fault detection paradigm. However, they are engaged in a number of ongoing programs and pilot projects involving energy information systems for commercial buildings, a roof top unit tune-up program, and soliciting customer and contractor feedback on energy use and equipment operation to help them manage energy use. See Appendix B for more information.

Key research questions:

1. Development of optimized PM schedules based on FDD alarms.

Research to reduce maintenance. Reducing maintenance on energy efficient equipment can help expedite uptake of the equipment. Downtime in itself can be wasteful and reduces service. Replacing equipment prematurely likewise increases embedded energy of equipment and reduces service.. Replacing equipment prematurely likewise increases embedded energy of equipment and reduces service.

Existing research: Research is ongoing at the National Institute of Standards and Technology (NIST) and the Western Cooling Efficiency Center (WCEC) at the University of California Davis, and the Energy Trust of Oregon (ETO) is also involved in this work in some capacity.

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Key research questions:

1. Questions not yet specified.

No current MTBF testing, case (i.e., California Energy Commission Title 24 goal for 2013). Need better information on the mean time between failures (MTBF) for different equipment in order to inform predictive maintenance programs and controls.

Existing research: None identified.

Key research questions:

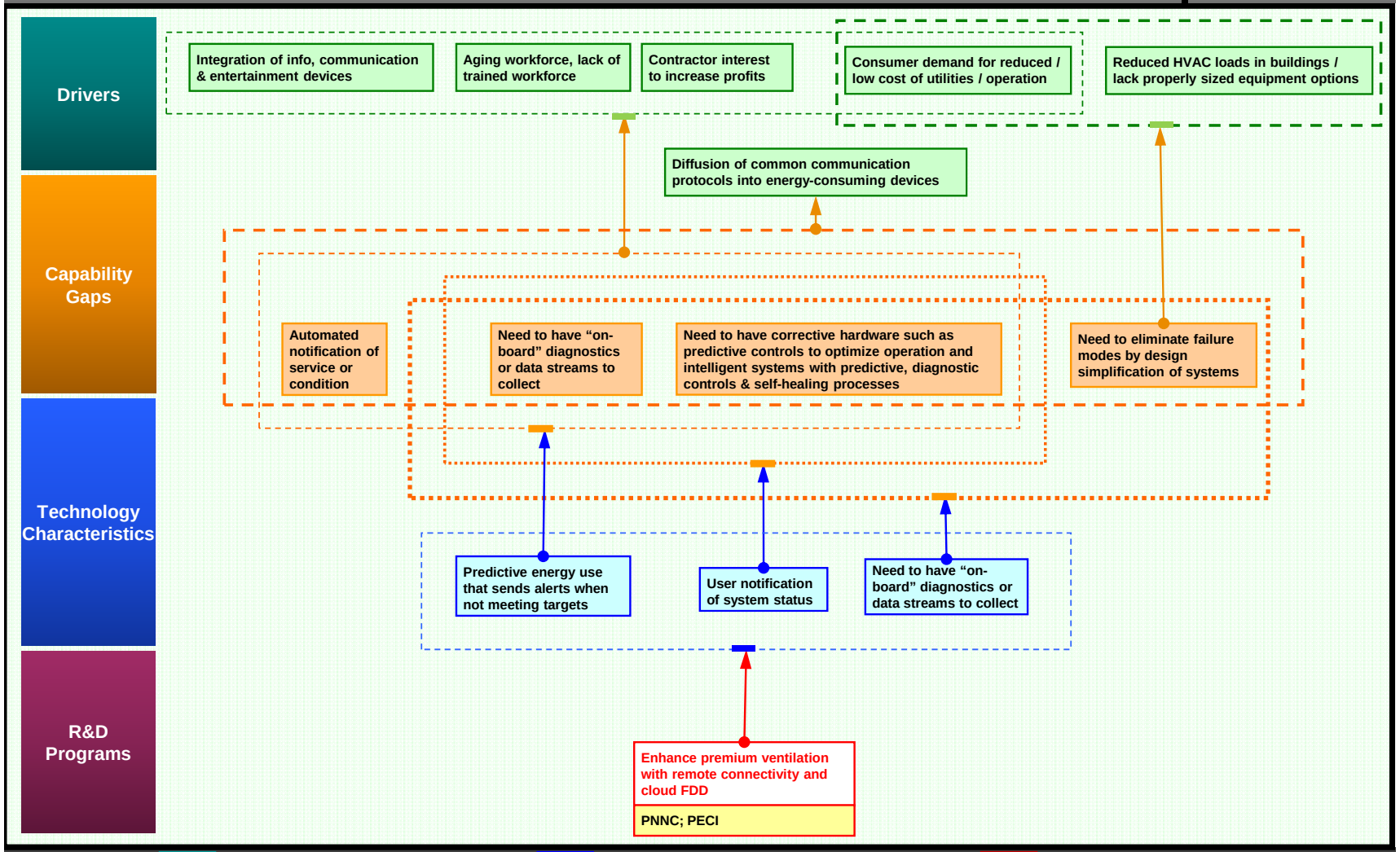
1. Can this be focused on faults in energy efficiency strategies?
2. Do high efficiency controls wear out equipment faster? If so, how to avoid this?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (8 of 13)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Enhance premium ventilation with remote connectivity and cloud FDD. Build on existing premium ventilation platforms to enhance fault diagnostics and multiple unit supervisory correction deployment.

Existing research: Pacific Northwest National Laboratory (PNNL).

- *[Summaries of existing research pending]*

Key research questions:

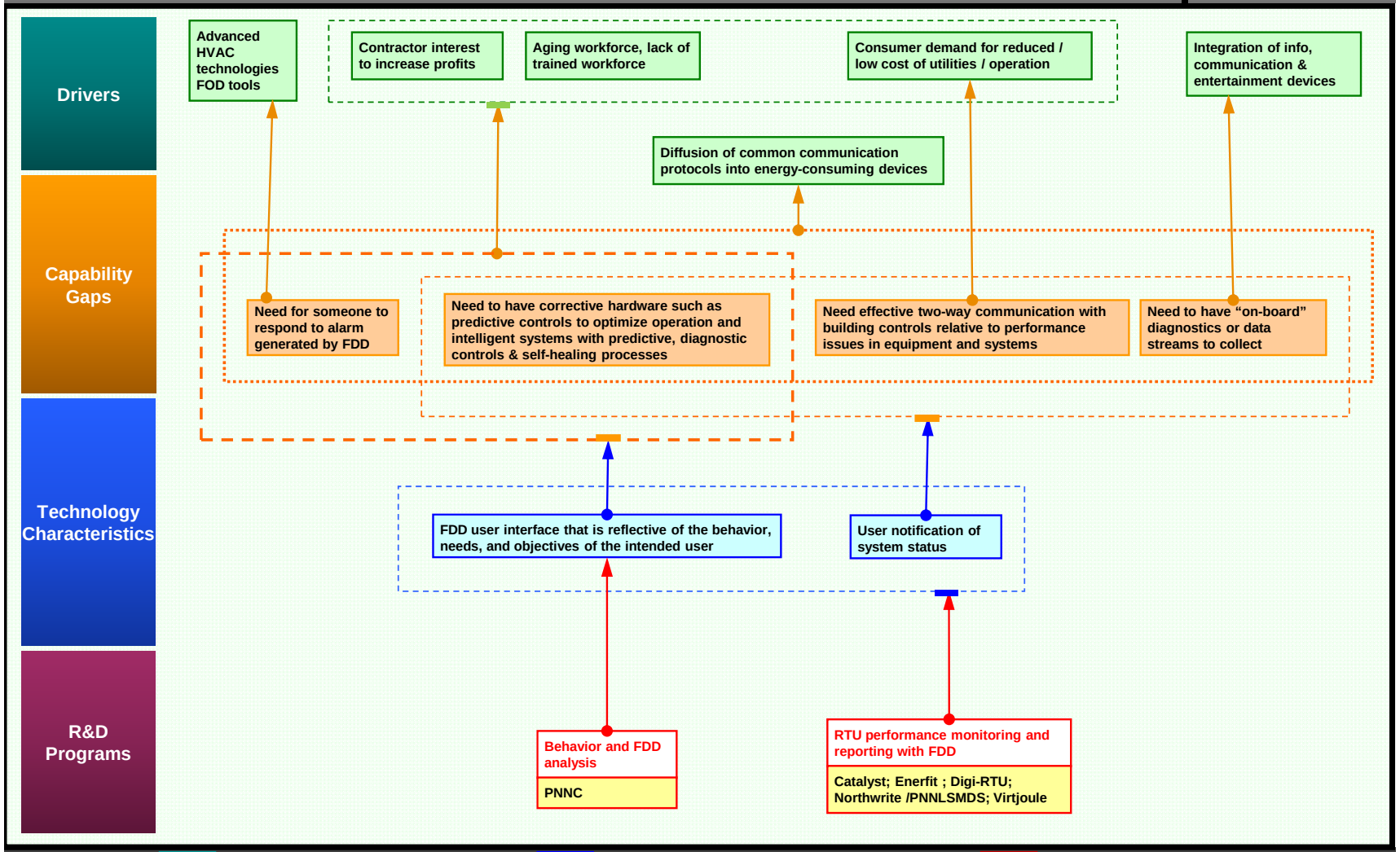
1. Determine the following:
   a. the impact on users to take corrective action;
   b. accuracy of improved FDD in detecting problems;
   c. improvement in scheduling with remote access to unit operation data; and
   d. portfolio energy improvement due to prioritization provided by FDD event screening software.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (9 of 13)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Behavior and FDD analysis. Develop an understanding of the behavior of building occupants, operators, and service contractors as it relates to the ability to respond to fault detection and diagnosis (FDD) alarms.

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC); Pacific Northwest National Laboratory (PNNL).

- *[Summaries of existing research pending]*

Key research questions:

1. How do occupants in small commercial buildings read to notifications?
2. How do building operators respond to alarms, depending on how they are annunciated?
3. How does FDD add value to a service contractor's business model?

RTU performance monitoring and reporting with FDD. Rooftop unit (RTU) embedded performance monitoring with fault detection and diagnosis (FDD) with the remote (off the roof) reporting to building and/or HVAC service or maintenance personnel (onsite or offsite).

Existing research: Catalyst, Enerfit, Digi-RTU, and Virtjoule. Also Northwrite / Pacific Northwest National Laboratory (PNNL) Smart Monitoring and Diagnostic System (SMDS) .

- *[Summaries of existing research pending]*

Key research questions:

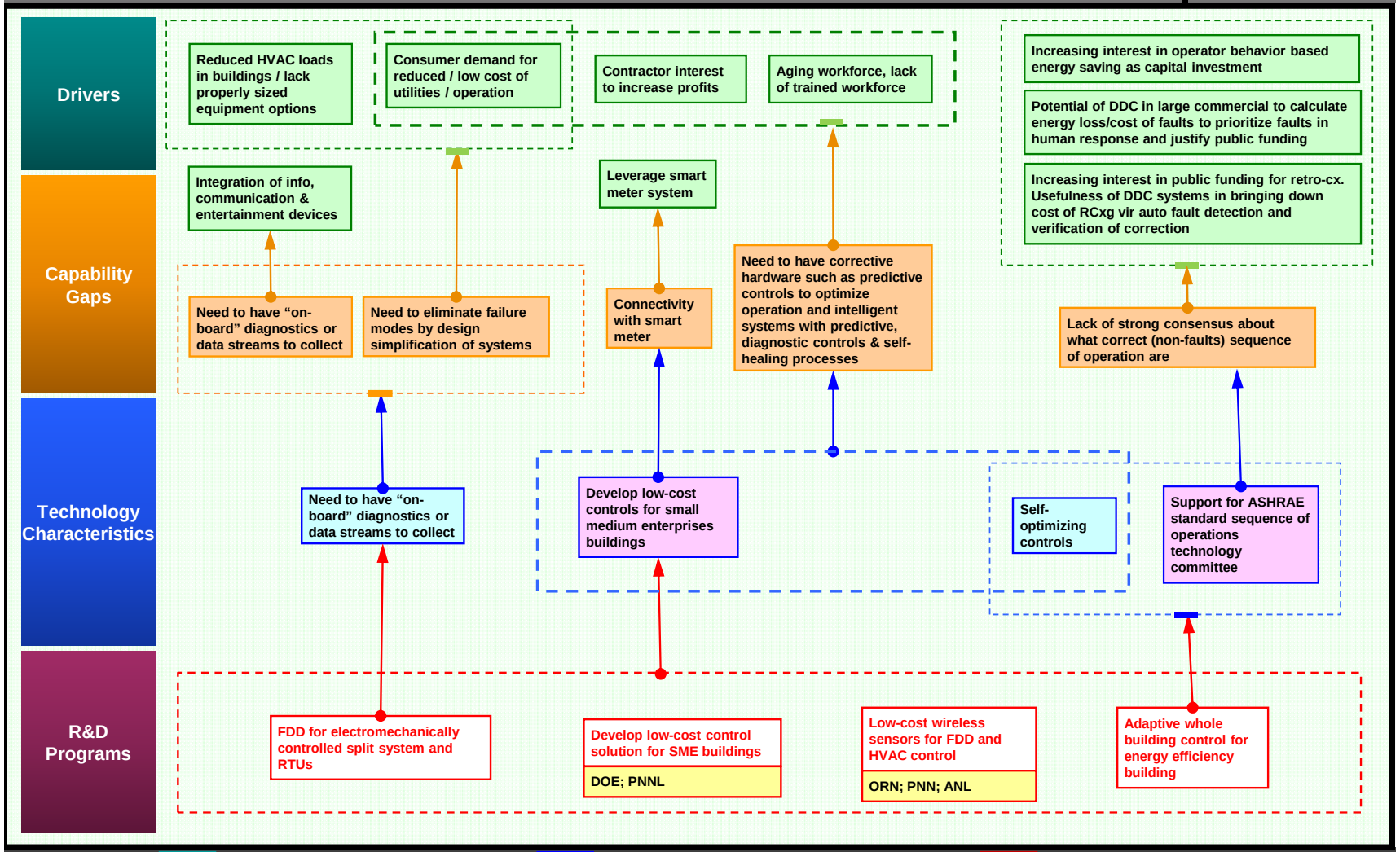
1. Investigate the high frequency of sensor failure due to:
   a. high/low charge alarm; compressor short cycling;
   b. low air flow;
   c. capacity and efficiency degradation;
   d. refrigerant non condensable; and
   e. high/low side HX problem.
2. Not economizing when it should or economizing when it should not.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (10 of 13)**

See "Technology Area Definitions" section



R&D Program Summaries

Low-cost wireless sensors for FDD and HVAC control. Ubiquitous low-cost sensors enable enhanced algorithms for fault detection and diagnosis (FDD) key in to develop sensors that are low-cost and easily deployable.

Existing research: Oak Ridge National Laboratory (ORNL), Pacific Northwest National Laboratory (PNNL), Argonne National Laboratory (ANL).

- *[Summaries of existing research pending]*

Key research questions:

1. How to do:
   a. system integration;
   b. interoperability;
   c. reliable sensing and transmission, and
   d. ultra low-cost driving deployment.

Develop low-cost control solution for SME buildings. Small and medium sized commercial building (typically less than 50,000 square feet) can reduced significant energy consumption (20%) if they are equipped with controls.

Existing research: U.S. Department of Energy (DOE) and Pacific Northwest National Laboratory (PNNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Develop low-cost control packages for SME buildings.
2. How to make SME buildings more energy efficient?
3. How to make SME buildings more demand responsive?

FDD for electromechanically controlled split system and RTUs. Investigate how economizers and thermostats might be used on rooftop units (RTUs) as a platform for fault detection and diagnosis (FDD).

Existing research: None identified.

Key research questions:

1. How can an economizer controller or a thermostat be used as a platform for FDD?
2. Develop algorithms for a split system and RTU's for economizer and thermostat based FDD.
3. Lab and field testing.

Adaptive whole building control for energy efficiency building. Advanced model-boned, model-predictive, learning-honed controller can improve energy efficiency and the building dynamically honed and building usage.

Existing research: None identified.

Key research questions:

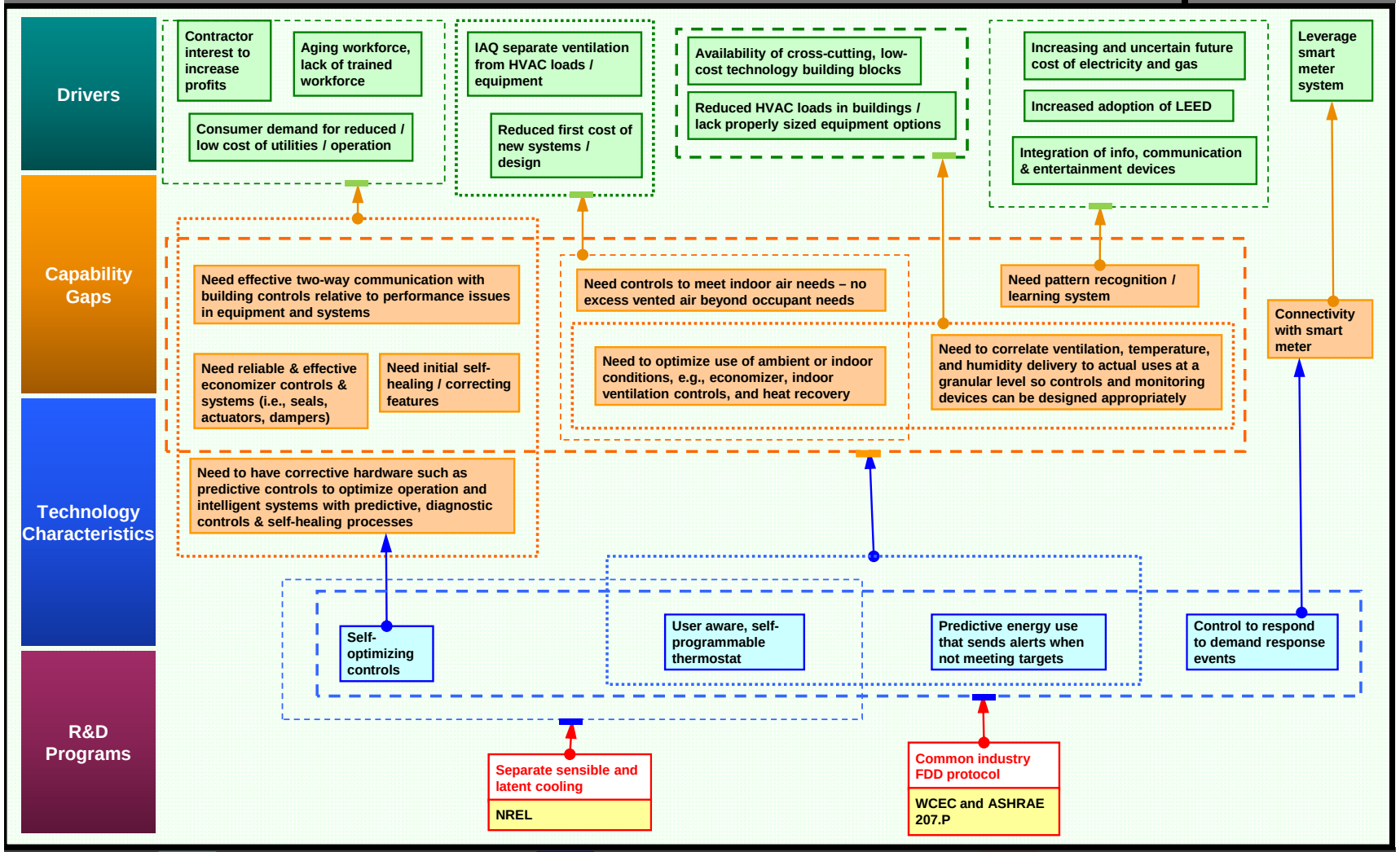
1. Develop open standard platform for deploying the controllers?
2. Sensors to enable improved observability of building behavior.
3. Computationally feasible implementation of controllers for building deployment.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (11 of 13)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Separate sensible and latent cooling. Elevated evaporator temperature can still meet sensible loads with less compressor work. A separate mechanism (low temperature evaporator or desiccant system) meets latent loads. A low temperature evaporator can work in parallel or the same evaporator can alternate between low and high temperature (sequential). Goal of this program is to evaluate savings and control options.

Existing research: National Renewable Energy Laboratory (NREL).

- *[Summaries of existing research pending]*

Key research questions:

1. Can any existing equipment be adapted to this strategy?
2. What sensing technologies for humidity can be cost effective?
3. What is increase in fan power?
4. What controls are required?

Common industry FDD protocol. Similar to automobile industry, develop a common "reader" protocols for fault detection and diagnosis (FDD) readout.

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC) and American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) Standard Project Committee 207.

- *[Summaries of existing research pending]*

Key research questions:

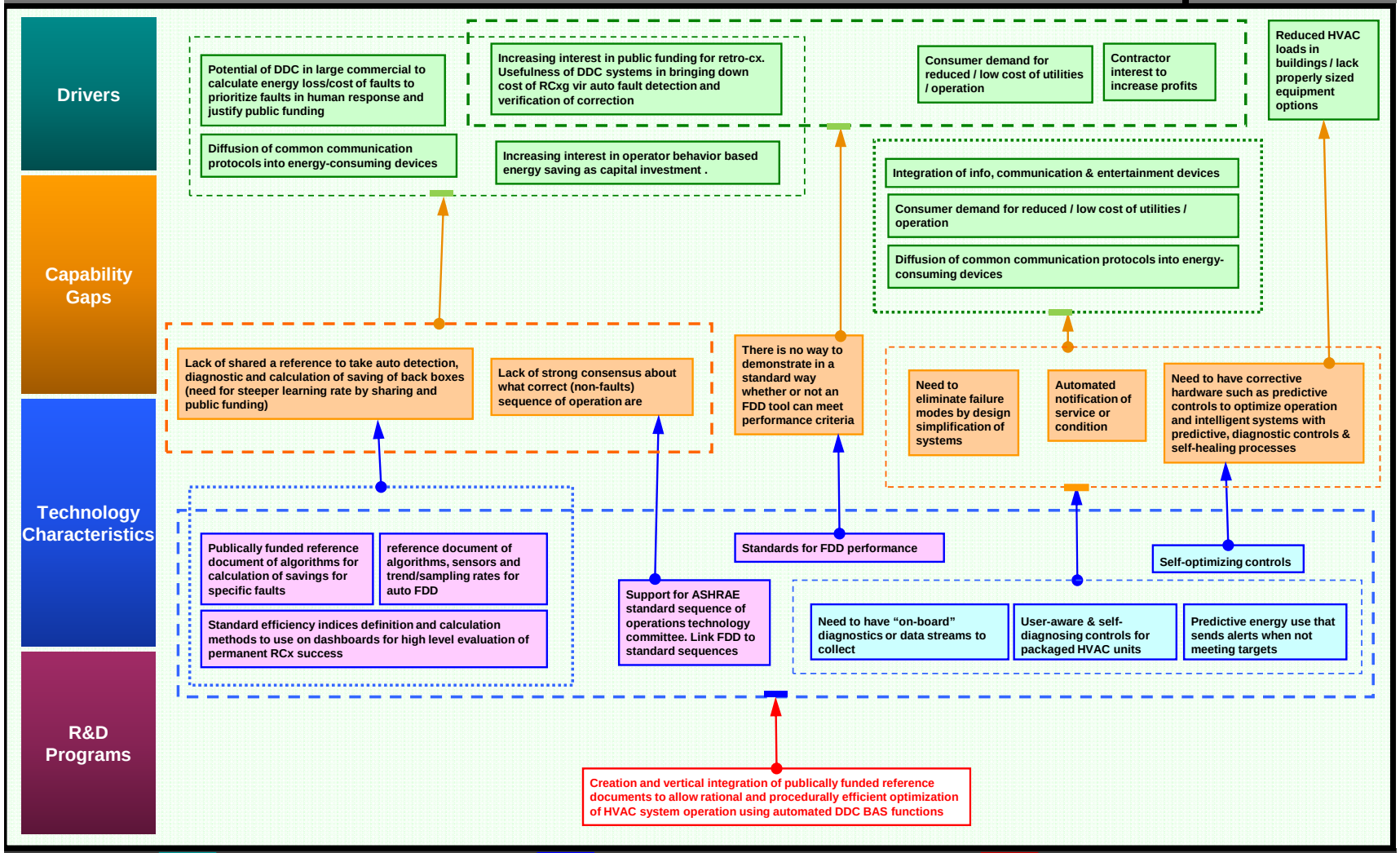
1. What general categories of faults need to be coded?
2. What hierarchy or structure of faults is good for categorization?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (12 of 13)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

Creation and vertical integration of publically funded reference documents to allow rational and procedurally efficient optimization of HVAC system operation using automated DDC BAS functions. Augment existing American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) standard control system sequence of operations where they relate to critical energy efficiency responses. Produce reference algorithms to calculate saving for above faults. Define overall indices to evaluate system performance using direct digital controller (DDC) for building automation systems (BAS) functions.

Existing research: None identified.

Key research questions:

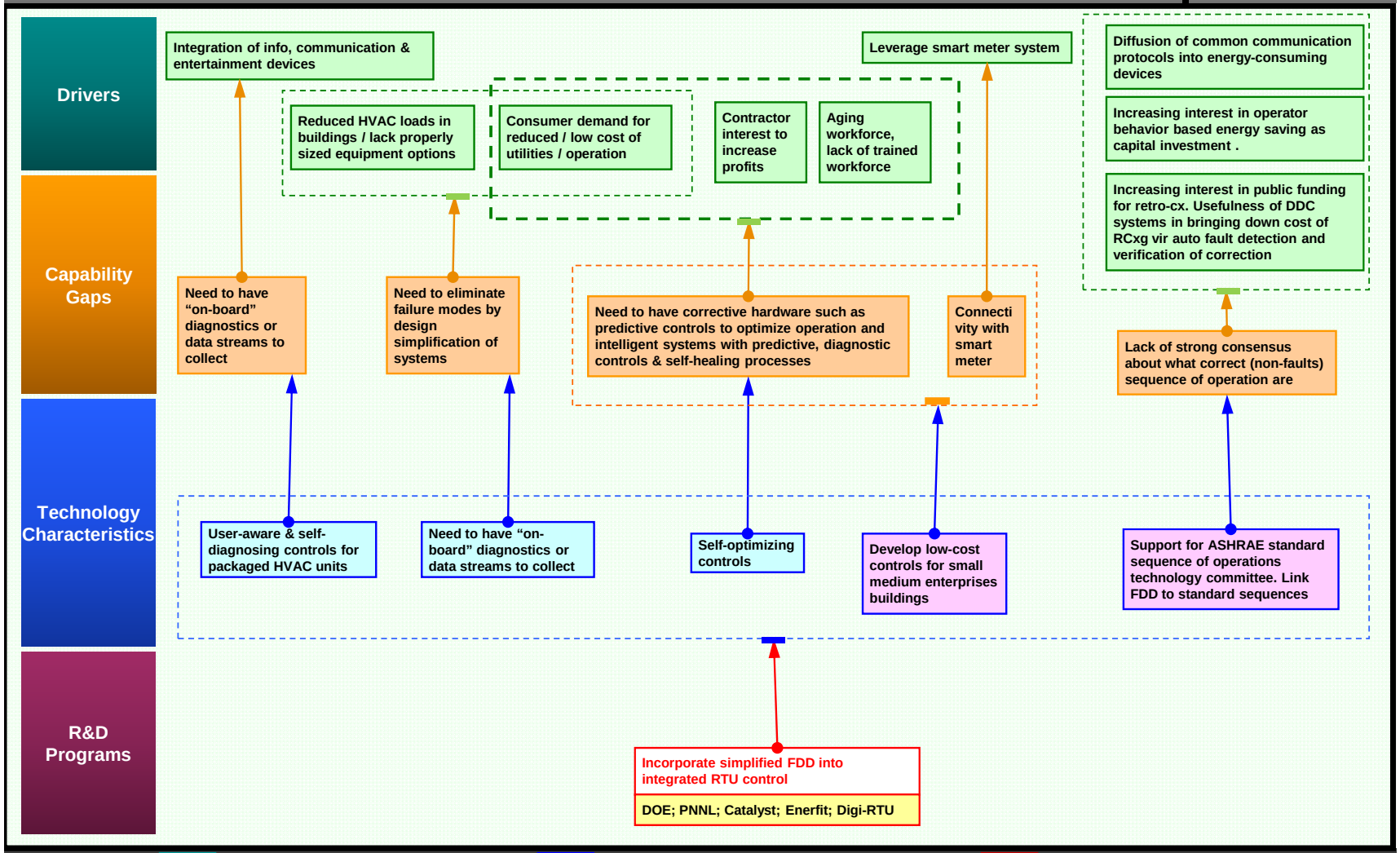
1. What is the best, simple, reliable and transparent algorithms for optimum starting, air side economizers, condenser meter, etc.?
2. What are the key physical characteristics for control system to achieve key sequences (sensor location/type, dumper value characteristics)?
3. For each critical factors, what are critical common failure patterns? How can they be automatically detected?
4. How can a DDC system be used to assess overall chilled water system performance?
5. How to calculate savings from identified default so operations and maintenance staff can prioritize response between multitudes of faults?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Fault Detection , Predictive Maintenance, and Controls (13 of 13)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Incorporate simplified FDD into integrated RTU control. Expand retrofit premium ventilation control (differential economizer and fan control) for rooftop units (RTUs) to include s basic fault detection and diagnosis (FDD) and streamlined setup.

Existing research: U.S. Department of Energy (DOE), Pacific Northwest National Laboratory (PNNL), Catalyst, Enerfit, Digi-RTU.

- *[Summaries of existing research pending]*

Key research questions:

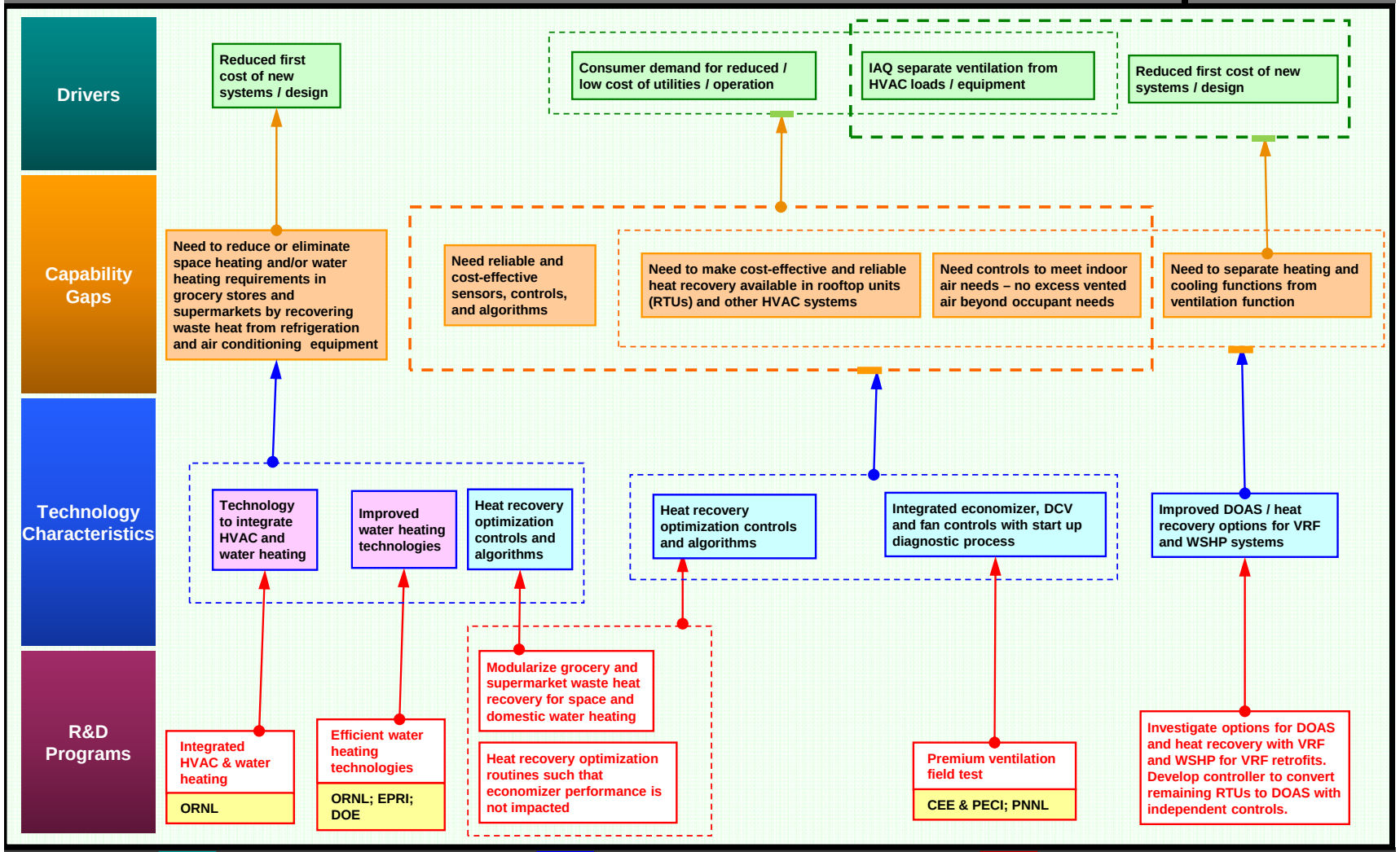
1. Can simplified set up diagnostics speed and improve contractor setup of RTUs?
2. Will simplified FDD programming fit into memory of available custom controllers?
3. In a multiple building field deployment, what is energy savings based on pre/post monitoring?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Heat Recovery and Economizer Optimization (1 of 2)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Premium ventilation field test. (Summary not yet provided.)

Existing research: Consortium for Energy Efficiency (CEE) & Portland Energy Conservation, Inc. (PECI), Pacific Northwest National Laboratory (PNNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Determine improvement in contractor ease of use.
2. Determine improvement in occupant ease of use.
3. Determine improvement in pre/post energy savings.

Integrated HVAC & Water Heating. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Efficient water heating technologies. (Summary not yet provided.)

Existing research: Oak Ridge National Laboratory (ORNL), Electric Power Research Institute (EPRI), U.S. Department of Energy (DOE).

- For ORNL's work in this area, see Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Continued . . .

Heat recovery optimization routines such that economizer performance is not impacted. Developing controls and system designs to optimize heat recovery and use of outside air can reduce or eliminate HVAC compressor and burner operation for many hours per year.

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Modularize grocery and supermarket waste-heat recovery for space and domestic water heating. Do a field study of using heat recovery from grocery refrigeration or air conditioning to use for space heating in other areas or to pre-heat domestic hot water.

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Investigate options for DOAS and heat recovery with VRF and WSHP for VRF retrofits. Develop controller to convent remaining RTUs to DOAS with independent controls. There have been cases where variable refrigerant flow (VRF) and water-source heat pumps (WSHPs) are retrofit and existing rooftop units (RTUs) remain for ventilation without integrated controls. Develop a controller / sequence for dedicated outdoor air systems (DOAS) that would operate the RTU on a cycling basis with demand-controlled ventilation (DCV) to maintain ventilation.

Existing research: None identified.

Key research questions:

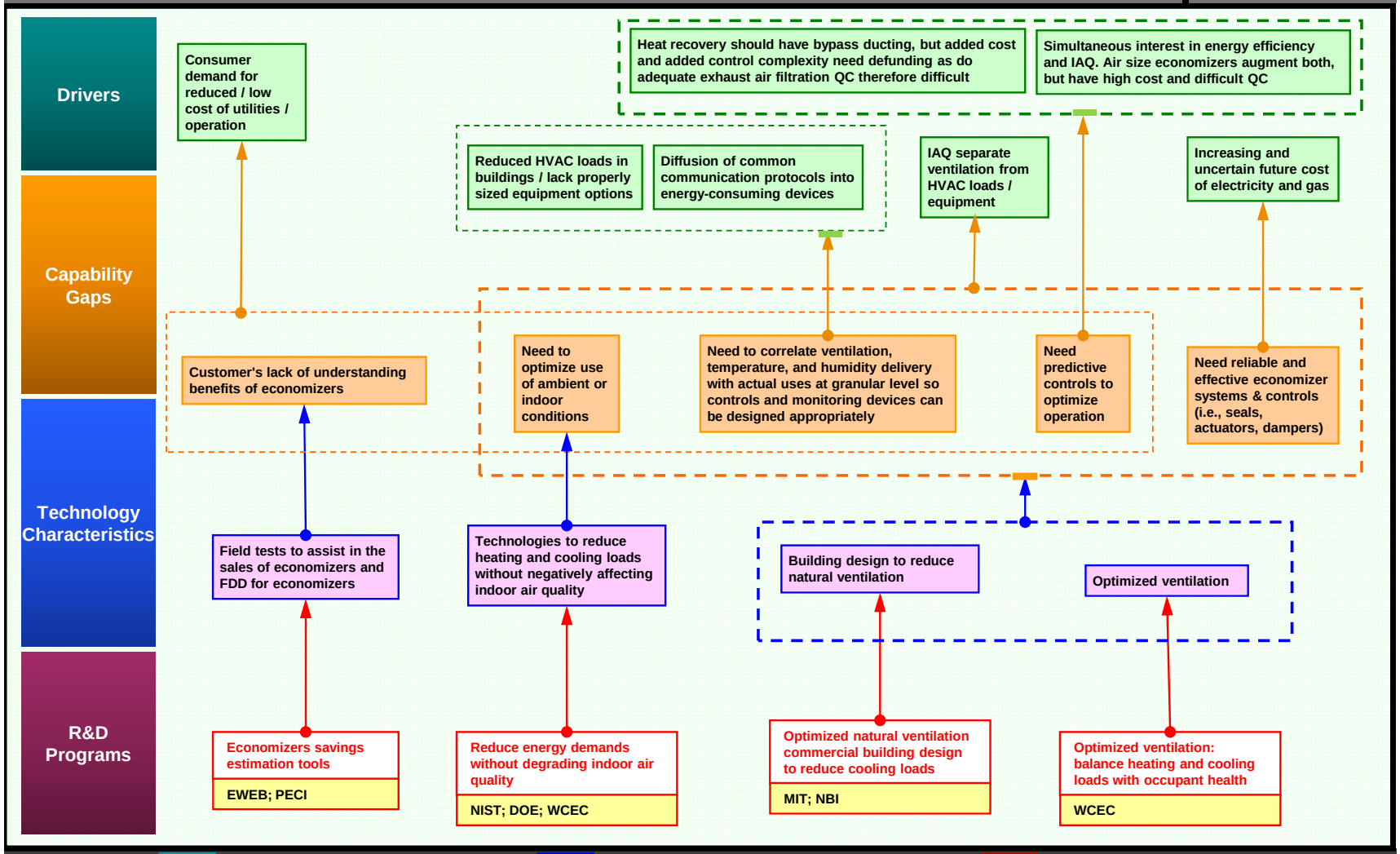
1. Can RTU be controlled independently based on schedule, DCV, and outside air?
2. What are potential savings compared to heat recovery DOAS?
3. What options for ventilation and ventilation heat recovery in DOAS systems exist?
4. How do these options compare as far as energy use?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Heat Recovery and Economizer Optimization (2 of 2)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Optimized natural ventilation commercial building design to reduce cooling loads.

Does fan mischarge pressure determine energy analysis results in comparing economizer cooling to variable refrigerant flow (VRF), chilled beam etc non economizer systems? If so, should we consider low pressure distribution systems?

Existing research: Massachusetts Institute of Technology (MIT), New Buildings Institute (NBI).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Economizer savings estimation tools.

Develop tools that can estimate the potential savings from installing an economizer or fixing a faulty economizer for a given application.

Existing research: Eugene Water and Electric Board (EWEB), Portland Energy Conservation, Inc. (PECI).

- *[Summaries of existing research pending]*

Key research questions:

1. Define requirements for such a tool.
2. Identify typical faults and their characteristics.
3. Develop a simplified model for energy use with and without a functioning economizer.
4. Characterize effects of minimum flow for ventilation, interior compared to perimiter zones. Integrated compared to unintegrated control with compressor operation. Climate high limit shutoff. Hours of operation per year. Supply air set point.

Reduce energy demands without degrading indoor air quality.

(Summary not yet provided.)

Existing research: National Institute of Standards and Technology (NIST), U.S. Department of Energy (DOE), University of California Davis Western Cooling Efficiency Center (WCEC).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Optimized ventilation: balance heating and cooling loads with occupant health.

(Summary not yet provided.)

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC).

- For WCEC research in this area, see Appendix B.

Key research questions:

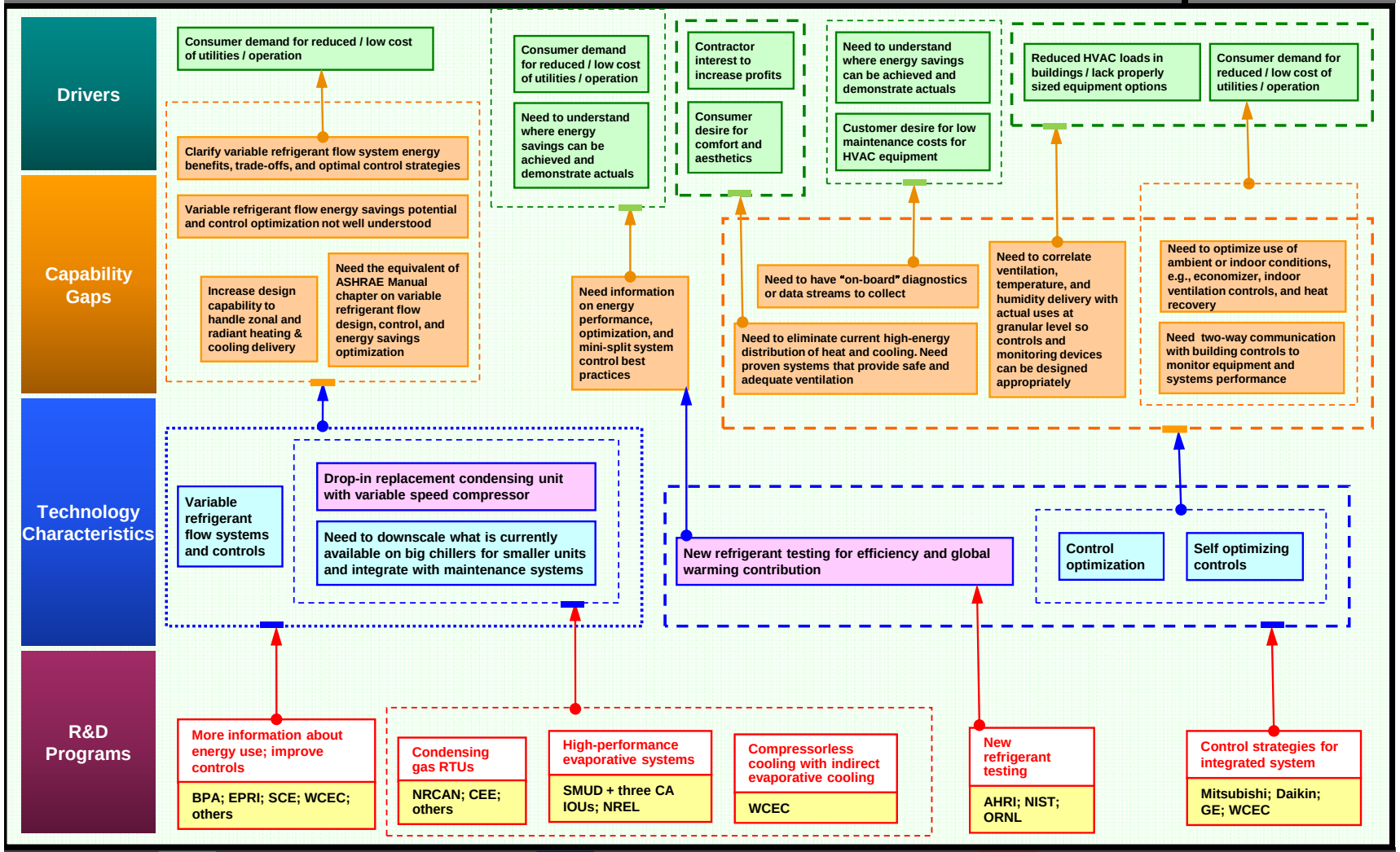
1. Questions not yet specified.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Heating & Cooling Production and Delivery (1 of 5)**

See "Technology Area Definitions" section



R&D Program Summaries

More information about energy use; improve controls. Develop reliable engineering and technical information on how to optimize variable refrigerant flow (VRF) energy savings while assuring comfort and reliability. Focus should be more on combination of demand control with VRF system to find the optimum approach.

Existing research: Bonneville Power Administration (BPA), Electric Power Research Institute (EPRI), Southern California Edison (SCE), University of California Davis Western Cooling Efficiency Center (WCEC), others.

- EPRI: See Appendix B.
- WCEC: See Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. What are the key parameters effecting VRF performance? Occupant behaviors within buildings and key parameters to affect the comfort (temperature, variants, pull down time).
2. Energy consumption of VRF under different scenarios needs to be analyzed. The key is to reduce the load so does the energy consumption.

New refrigerant testing. AHRI has an ongoing research program. Low-GWP alternative refrigerants evaluation program (Low-GWP AREP). The purpose of the program is to test potential high GWP refrigerant replacements. Testing is done in accordance with industry-wide accepted standards.

Existing research: Air-Conditioning, Heating, and Refrigeration Institute (AHRI), National Institute of Standards and Technology (NIST), Oak Ridge National Laboratory (ORNL).

- ORNL: See Appendix B.
- NIST: See Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. The performance of alternate refrigerant candidates will be presented.

Condensing gas pack RTUs. Roof-top units (RTUs) with condensing gas heat will be much more efficient than non-condensing. Field test as necessary and encourage implementation in the Northwest.

Existing research: Stakeholders indicated that work in this area is ongoing at the Consortium for Energy Efficiency (CEE) and Natural Resources Canada (NRCAN); CEE staff member Tony Gross has also indicated that Douglas Kosar at the Gas Technology Institute and Dick Lord at Carrier Corporation have expertise in ongoing research in this area, and BPA staff is in the process of following-up with these contacts.

- Martin Thomas oversees NRCAN (http://www.nrcan.gc.ca/home) research in this area.
- CEE does not conduct its own technical research in this area, but does keep abreast of R&D and helps bring emerging technologies into the marketplace; see http://www.cee1.org/.
- Gas Technology Institute: http://www.gastechnology.org/webroot/app/xn/xd.aspx?it=enweb&xd=gtihome.xml.
- Carrier Corporation: http://carrier.com/Carrier+Corporate+Sites/Corporate

Key research questions:

1. Questions not yet specified.

Continued . . .

Control strategies for integrated system. Understand the process of integrated systems (water heating and cooling together). How to optimize the two processes?.

Existing research: Mitsubishi, Daikin, General Electric (GE), University of California Davis Western Cooling Efficiency Center (WCEC).

- WCEC: See Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. What are the load profile and draw pattern?
2. What is the optimum size of water storage?
3. What are the limits?

High-performance evaporative systems. Seely International of Australia reports cooling by indirect / direct means with drops in temperature approaching dew point and using one-half of the water of either direct / indirect systems. Test in a variety of hot-dry locations from Boise (ID) to Borrego Springs (CA) and Salt Lake City (UT) to confirmed and document performance in systems of varying sizes.

Existing research: Sacramento Municipal Utility District (SMUD) and the three IOUs in California are poised to begin testing Summer 2013. Research also ongoing at National Renewable Energy Laboratory (NREL).

- NREL: See Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. Can evaporative systems produce temperature drops of 50 to 60 degrees Fahrenheit?
2. What is the level of water consumption?
3. What is the physical weight and size of high performance evaporative systems?
4. Are the system controls well developed including fault detection?
5. Is the manufacturer continuing to refine the product to improve performance and reduce cost?

Compressorless cooling with indirect evaporative cooling. Purpose: Method test for indirect evaporative cooling and distribution of energy efficiency. Scope: Residential indirect evaporative cooler. Goals: Generic test and performance specifications for effective and efficient units that support market uptake and induction of multiple systems.

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC).

- *[Summaries of existing research pending]*

Key research questions:

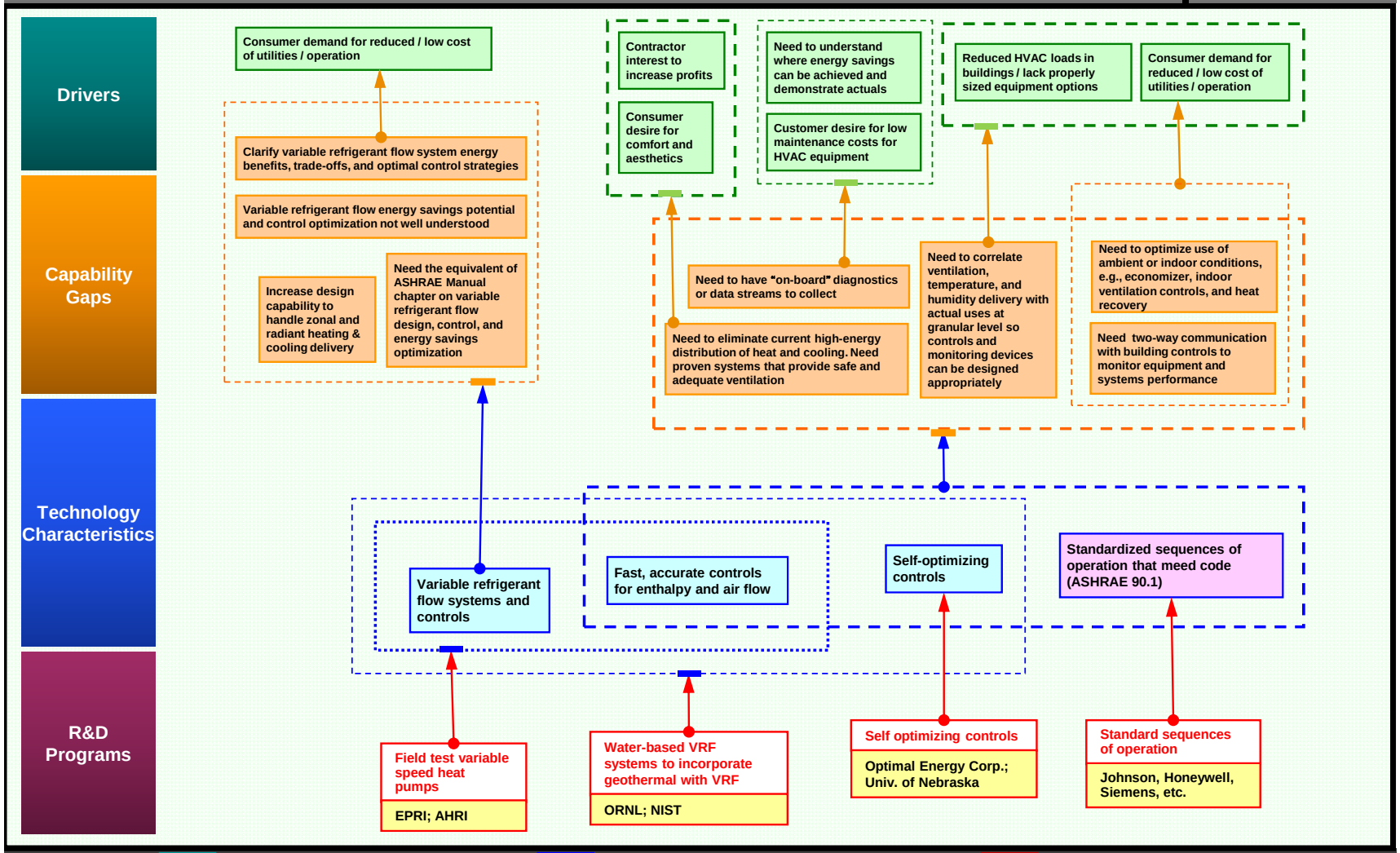
1. What shall be the method of test for indirect evaporative cooling?
2. What performance and design metrics are required to support market adoption?
3. What shall be the water use metric and criteria. Gallons/how?
4. What shall be required for water quality management?
5. Define the installation and maintenance requirements for indirect evaporative codes.
6. What are the relief/exhaust options for correct operation?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Heating & Cooling Production and Delivery (2 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Field test variable speed heat pumps. One of the most promising heating and air conditioning technologies is variable refrigerant flow, or "multi-split" systems. However, good field testing is needed to verify that it can perform in the field as promised in theory.

Existing research: Stakeholders reported that the Electric Power Research Institute (EPRI) was conducting research in this area specifically with technologies developed by Daikin Industries. Subject matter experts also indicated that the Air-Conditioning, Heating, and Refrigeration Institute (AHRI) was also working in this area.

- EPRI: See Appendix B.
- *[Summaries of other existing research pending]*

Key research questions:

1. What applications will provide the best savings to the utility?
2. What is the efficiency of the heat recovery function?

Water-based VRF systems to incorporate geothermal with VRF. So much attention has been given to air-source heat pumps recently that the variable refrigerant flow (VRF) "multi-split" and "mini-split" systems are nearly as efficient as ground-source and water-source heat pumps. Could we combine the technologies, using what we have learned in VRF technology to further increase the efficiency of water-source heat pumps? Both Mitsubishi and Daikin Industries, Ltd., offer products that represent some progress in this area.

Existing research: Oak Ridge National Laboratory (ORNL), National Institute of Standards and Technology (NIST).

- *[Summaries of existing research pending]*

Key research questions:

1. What is the cost premium of water based systems vs air source?
2. What is the cost of the ground heat exchanger?
3. How does the cost of VRF geothermal does compared to geothermal w/ hydraulic heat pumps?

Continued . . .

Self optimizing controls. Research existing and potential self optimizing controls. What are the key savings available for a "Hartman Loop" for packaged HVAC equipment?.

Existing research: Optimal Energy Corporation, University of Nebraska.

- Subject matter experts reported in September 2012: "Haorong Li @ U. of Nebraska Omaha's Virtual Sensor."
- *[Summaries of existing research pending]*

Key research questions:

1. Can principles from Hartman's control be applied to unitary equipment?
2. Can condenser fan speed, compressor speed, and indoor fan speed be modulated based on total power input?
3. What energy savings are possible through power-based control algorithms for packaged equipment?
4. What additional sensors are required for power-based control?
5. What is the additional cost for power-based control?

Standard sequences of operation. Research the availability or potential of standard sequences of operation that meet code and can easily be incorporated into control designs.

Existing research: Johnson, Honeywell, Siemens, etc.

- *[Summaries of existing research pending]*

Key research questions:

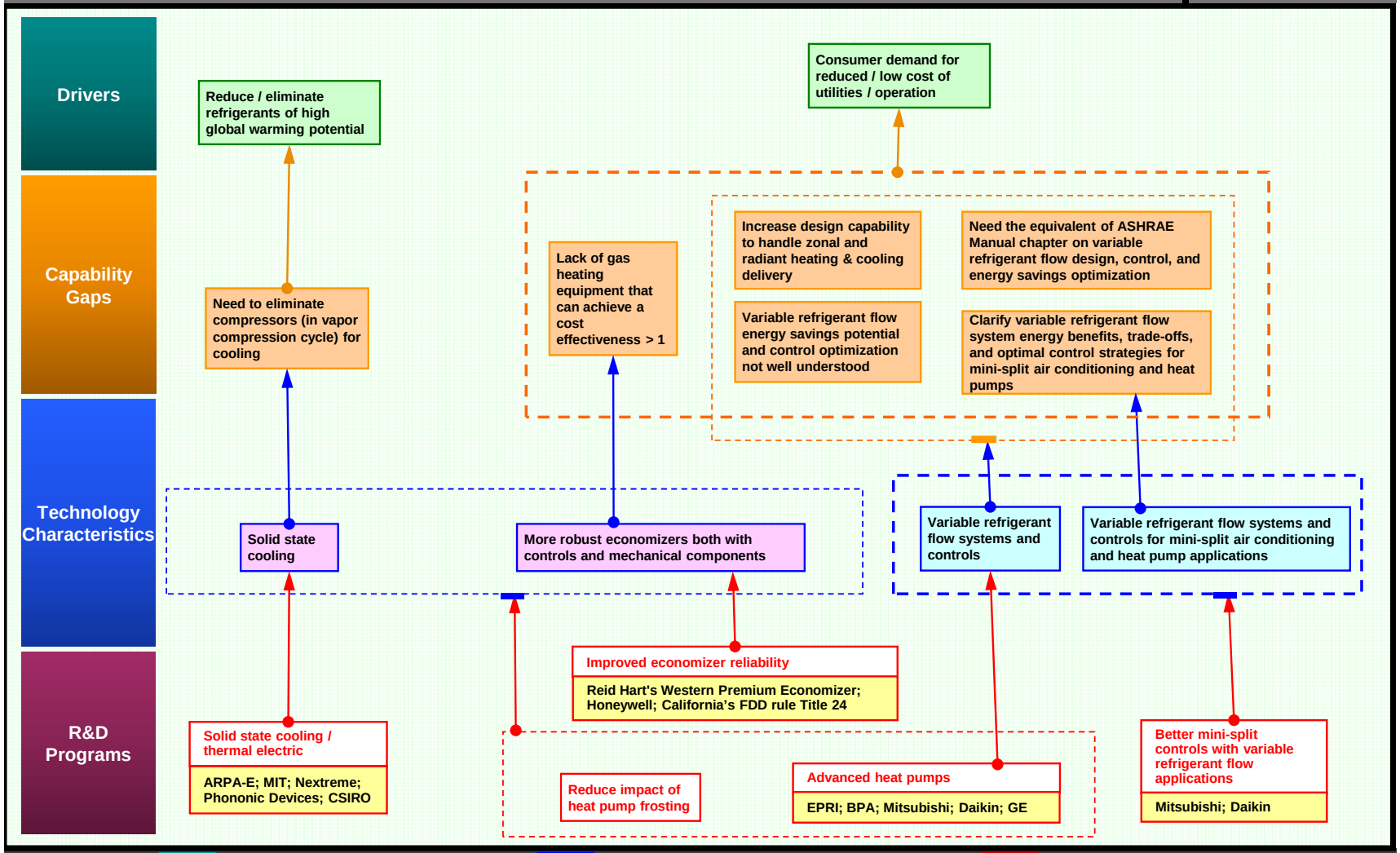
1. Are there standard sequences already available?
2. Can sequences be made available in an open source format (i.e., BACnet communications protocol for building automation and control networks)?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Heating & Cooling Production and Delivery (3 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Solid state cooling / thermal electric. Increase the efficiency of cooling through thermoelectric devices.

Existing research: ARPA-E, Massachusetts Institute of Technology (MIT), Nextreme, Phononic Devices, Commonwealth Scientific and Industrial Research Organisation (CSIRO)

- *[Summaries of existing research pending]*

Key research questions:

1. Can the technology be scaled?
2. Where can it be applied to conventional systems to improve efficiency?

Advanced heat pumps. Advanced HP for all climates. High COP to provide services to the grid (ancillary services).

Existing research: Electric Power Research Institute (EPRI), Bonneville Power Administration (BPA), Mitsubishi, Daikin, General Electric (GE).

- Thirty-five subject matter experts representing Bonneville Power Administration (BPA), the Electrical Power Research Institute (EPRI), Southern California Edison (SCE), and seventeen other institutions collaborated from 2009-2011 to produce the Variable Capacity Heat Pump Measure Development Roadmap (http://www.bpa.gov/energy/n/emerging_technology/VCHPOverview.cfm). As part of this effort, BPA contracted EES Consulting of Kirkland, Washington, to perform secondary research and provide estimates of efficiency improvements in the Northwest by applying variable capacity heat pump technology; see "Measure Summary Report: Variable Refrigerant Flow," February 2011, http://www.bpa.gov/energy/n/emerging_technology/pdf/BPA_VRF_Measure_Report_Final_R1.pdf.
- EPRI continues to conduct laboratory testing and modeling of advanced variable refrigerant flow systems in partnership with SCE and the Florida Solar Energy Center (FSEC) and funding from BPA's Energy Efficiency Emerging Technology (E3T) team; more information in Appendix B.

Key research questions:

1. With grid connectivity effect of cycling compressor impact to HP efficiency.
2. Trade-offs of HP vs system (grid) efficiency.

Continued . . .

Better mini-split controls with variable refrigerant flow applications. Variable refrigerant flow (VRF) and other control optimization can make mini-splits even better alternatives to conventional central air conditioning. Investigate energy savings of mini-splits and multi-splits with occupancy sensors.

Existing research: Mitsubishi, Daikin.

- *[Summaries of existing research pending]*

Key research questions:

1. What are the fan and cooling & heating energy savings associated with using several zones with occupancy controls?
2. What kind of a setback is required for any significant energy savings?
3. Is there a homeowner, customer, or business owner comfort issue from setting back zones?

Improved economizer reliability. Research ways to improve economizer functionality and reliability. Test existing products for sequence functionality and reliability.

Existing research: Reid Hart's Western Premium Economizer, Honeywell, California Title 24.

- *[Summaries of existing research pending]*

Key research questions:

1. Is there any hope for an enthalpy economizer?
2. Can humidity sensors ever be accurate and reliable enough?
3. Are there other sensors than relative humidity (RH) (wetbulb) that can be used to determine enthalpy?
4. Can mechanical components of economizers be improved—i.e. move away from single actuator to dual actuators without linkage?
5. Do any products currently available (Honeywell JADE) provide acceptable reliability?

Reduce impact of heat pump frosting. Frosting of heat pump evaporator coils and the accompanying need for thermal defrosting is a significant energy penalty.

Existing research: None identified.

Key research questions:

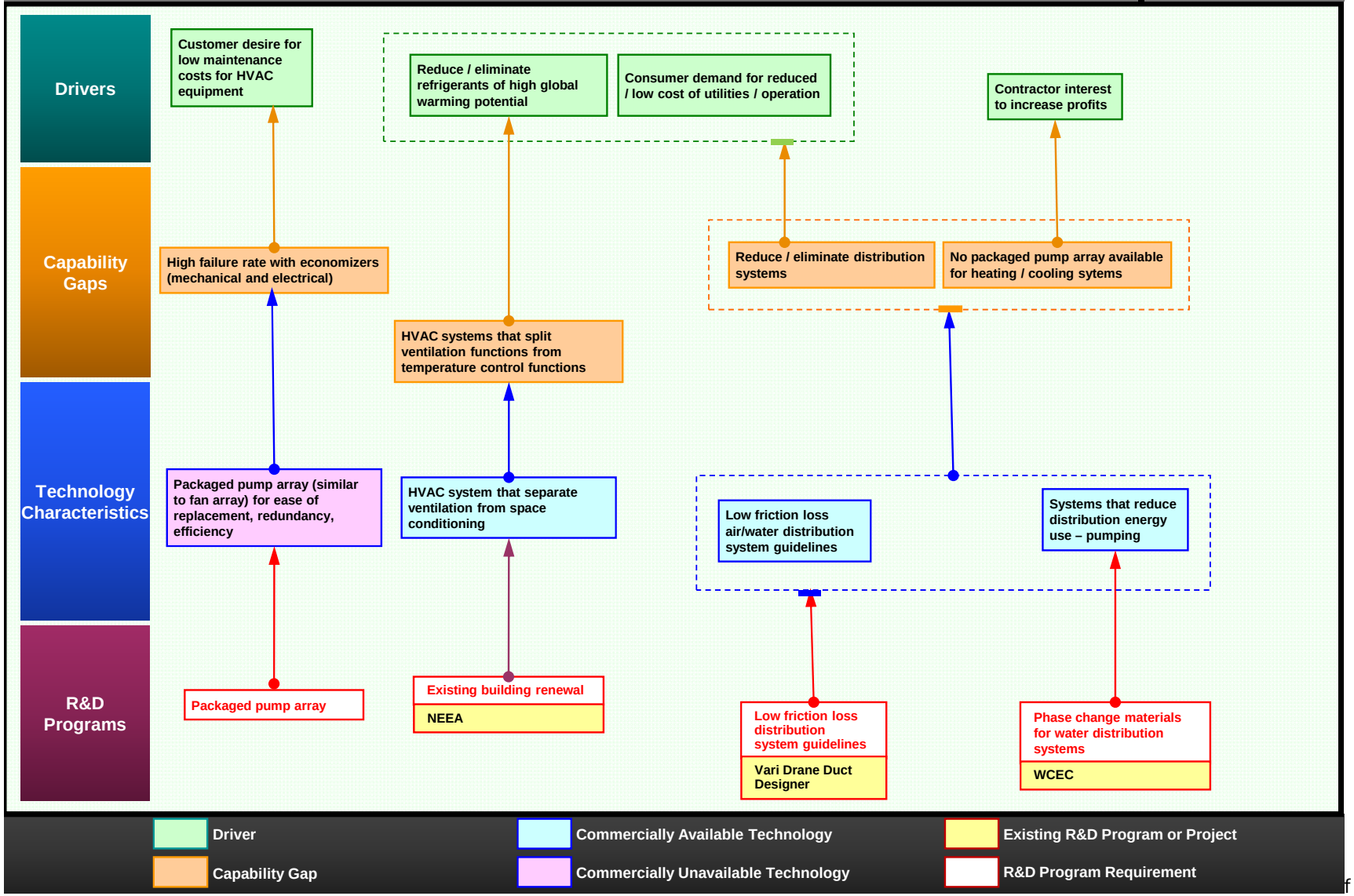
1. How can frost formation be minimized?
2. How can frost removal be optimized?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Heating & Cooling Production and Delivery (4 of 5)**

See "Technology Area Definitions" section



R&D Program Summaries

Existing building renewal. Field demonstrations of deep retrofits of HVAC systems, especially large commercial buildings. Facilitate more to separating ventilation or conditioned air and equipment downsizing through system integration.

Existing research: Northwest Energy Efficiency Alliance (NEEA).

- *NEA: Existing Building Renewal Initiative (BetterBricks): http://www.betterbricks.com/design-construction/existing-building-renewal-initiative.*

Key research questions:

1. Demonstrate savings from deep retrofits of HVAC systems.

Low friction loss distribution system guidelines. Develop guideline for the design of low friction loss air and water distribution systems.

Existing research: Vari Drane Duct Designer.

- *[Summaries of existing research pending]*

Key research questions:

1. Can key principles of low friction loss systems be incorporated into a guideline or software package for duct and pipe systems?
2. Can a pocket guide be erected?
3. Can an existing duct/pipe software package be use to offer low friction design advice?
4. Software could issue warnings if high loss fittings were used.

Phase change materials for water distribution systems. Investigate the potential for pumping energy savings from injecting phase change "beads" into pumped water or glycol.

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC).

- *[Summaries of existing research pending]*

Key research questions:

1. Model the potential savings.
2. Durability, pump interactions, feasibility.
3. Lab test.
4. Field test / demonstration.

Packaged pump array. Research energy efficiency benefits of packaged pump array including benefits of redundancy and ease of replacement.

Existing research: None identified.

Key research questions:

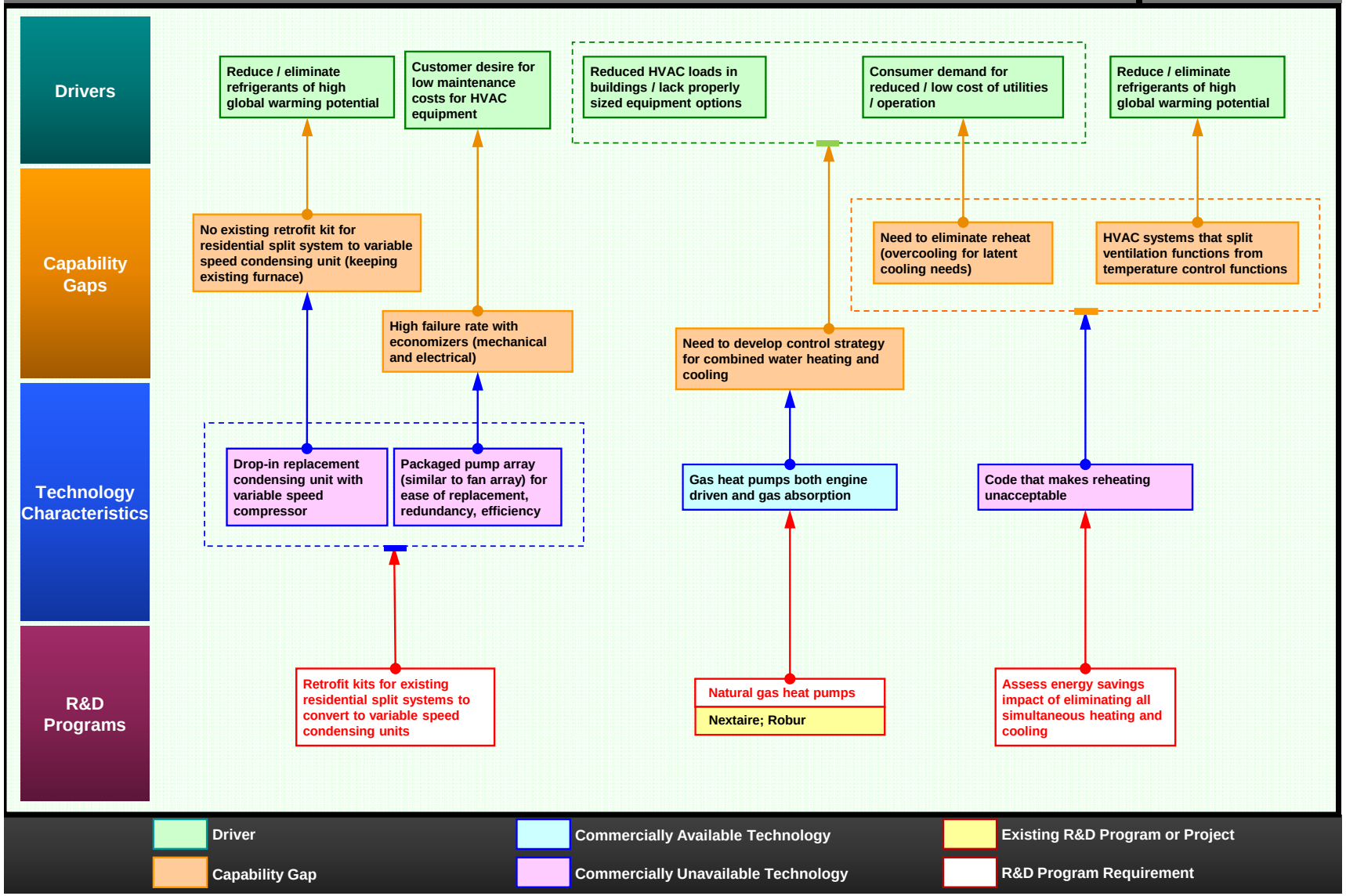
1. What are the efficiency gains possible with multiple pump arrays? (i.e. 4 or more)
2. Can arrays be produced cost effectively?
3. What is the payback / life-cycle cost (LCC) of pump arrays?
4. Can pump arrays be built of commonly available pumps?
5. How would such an array be controlled?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Heating & Cooling Production and Delivery (5 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Natural gas heat pumps. Investigate the potential of natural gas heat pumps both engine driven and absorption technologies.

Existing research: Nextaire, Robur.

- *[Summaries of existing research pending]*

Key research questions:

1. What are the maintenance costs associated with gas engine driven equipment?
2. What is the payback period for both types of gas heat pumps?
3. What is the reliability of equipment with an internal combustion engine?
4. Are specialized skills required of maintenance personnel?
5. Are there performance challenges with gas absorption heat pumps?

Retrofit kits for existing residential split systems to convert to variable speed condensing units. Examine the technical hurdles to producing a retrofit kit that could allow homeowners to change their existing fixed-speed condensing units to variable speed units without changing their indoor furnace or air handling unit (AHU).

Existing research: None identified.

Key research questions:

1. Does the existing thermostatic expansion valve (TXV) need to be changed out?
2. Can the existing constant speed indoor fan be kept? Is a variable speed indoor fan required?
3. Could a single phase variable frequency drive (VFD) or electronically commutated motor (ECM) replacement be used to convert the indoor unit to variable speed?
4. Are there products on the market already that do this? What is the potential market?

Assess energy savings impact of eliminating all simultaneous heating and cooling. Systems such as Variable air volume (VAV) with reheat or similar systems that result in simultaneous heating and cooling waste energy for the most part because they try to heat/cool and ventilate. How many of these systems are installed each year and how much energy is wasted?.

Existing research: None identified.

Key research questions:

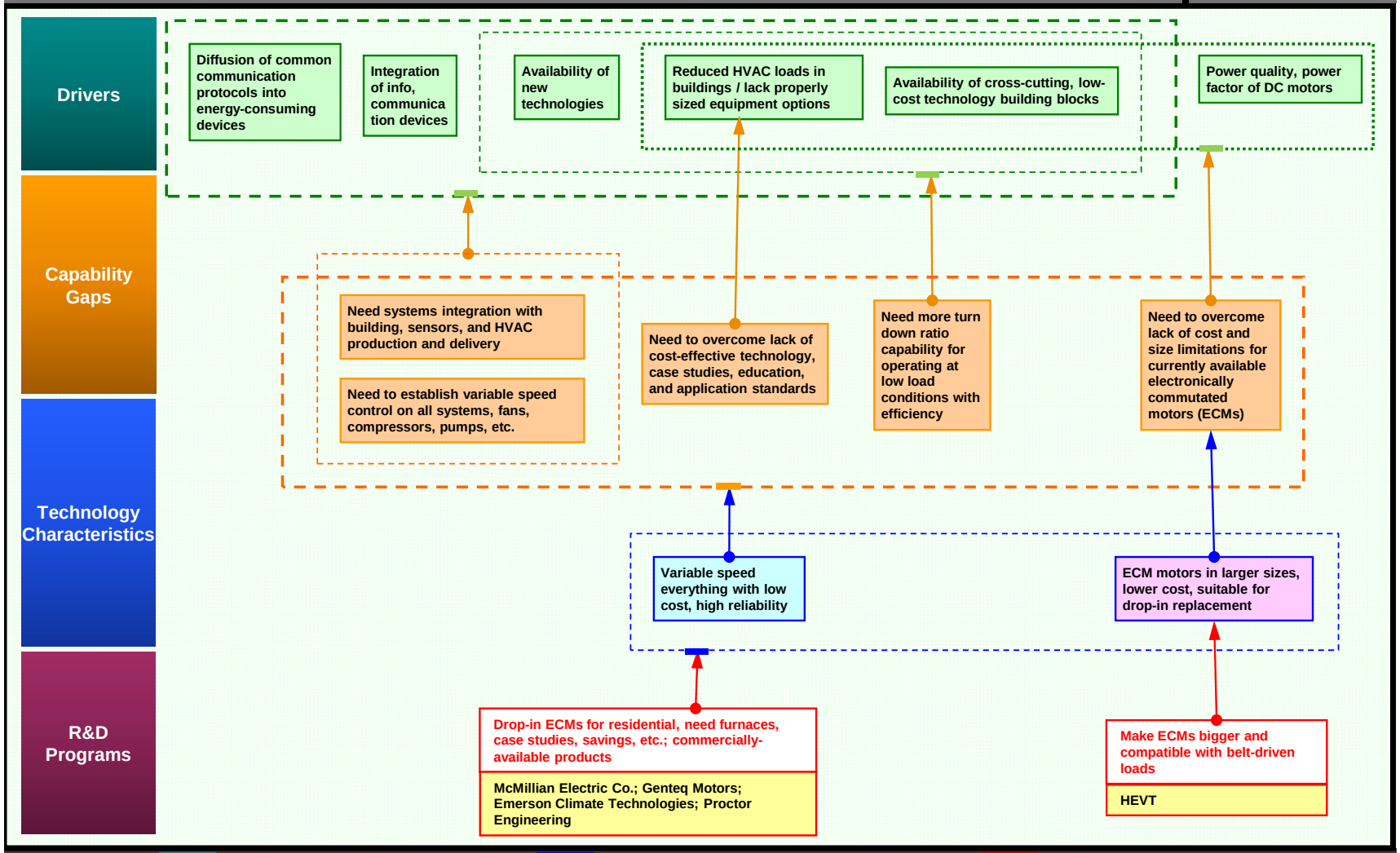
1. What is the market size for systems that do simultaneous heating and cooling?
2. How much energy is wasted?
3. What is the cost impact of eliminating these systems from the market and replacing with systems that do not simultaneously heat/cool e.g. dedicated outdoor air systems (DOAS) ventilation systems coupled with variable refrigerant flow (VRF), or radiant or chilled beam?
4. What are other options for systems that can heat/cold/ventilate without simultaneous heating and cooling?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **HVAC Motor-driven Systems (1 of 2)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Drop-in ECMs for residential, need furnaces, case studies, savings, etc.; commercially-available products. Use of electronically commutated motors (ECMs) for small motors could decrease energy use and increase ease of speed control significantly. A line of ECMs that would drop-in easily for retrofits would make implementation easier and more widespread.

Existing research: McMillian Electric Co., Genteq Motors, Emerson Climate Technologies, Proctor Engineering.

- As of January 2011, E Source reported that there were at least three commercially-available options for drop-in replacement brushless permanent magnets (BPM, a.k.a., electronically commutated motors) for furnace and/or air conditioning motors (see http://www.esource.com/node/27096); these included
  - McMillian Electric Company (http://www.mcmillanelectric.com/) offers the high-efficiency Concept 3 motor with climate optimized controls for standard heating and air conditioning systems (http://www.proctoreng.com/c3motor.html).
  - Genteq Motors (http://genteqmotors.com/) offers the Evergreen IM high-efficiency ECM designed to replace HVAC system blower motors. (http://genteqmotors.com/products/genteq/evergreen-im/).
  - Emerson Climate Technologies (http://www.emersonclimate.com/en-US/Pages/Home.aspx) offers the Rescue Ecotech® is designed to drop-in to existing permanent split capacitor blower applications, and does not require complex wiring modifications or system control changes (http://www.emersonclimate.com/en-US/products/motors/variable_speed_ecm/rescue_ecotech/Pages/rescue_ecotech.aspx).
- *[Summaries of existing research pending]*

Key research questions:

1. What electrical or control modifications are required?
2. What are actual savings achievable for various replacements?
3. What applications are the best for variable speed retrofit i.e. can a variable speed ECM motor be used without having to make modifications to many other components?
4. What applications are the best for constant speed retrofit only, i.e. systems not really capable of variable speed operation, but would benefit from a more efficient ECM motor running at constant speed?
5. How much energy can be saved by doing balancing with the ECM motor in use of closing all the dampers?

Make ECMs bigger and compatible with belt-driven loads. Electronically commutated motors (ECMs) have been very effective for saving energy and simplifying speed control for small motors. Having them available in larger sizes could simplify many retrofits, increase efficiency, and simplify design of variable speed systems.

E Source reported in January 2011 that they were not aware of any current research into very large ECMs, because as ECM motor size increases, the technology has to compete with highly efficient 3-phase motors. Research in electric vehicle technologies is illustrative. E Source Research Manager Bryan Jungers reported that his analysis of direct current-permanent magnet (DC-PM) motors in comparison to alternating current (AC) induction motors showed that the DC motors tended to be 10 to 20% more energy efficient on average in the 75kW range. For larger motors (~200+ kW), however, the AC induction motor is the preferred option, as it is usually smaller, lighter, and less expensive. For applications less than or equal to about 50 kW, the PM motors seem to have a size and weight advantage, partly due to their smaller and lighter motor controller. In the range of 50 to 150 kW, the market seems somewhat split on these two options: for heavy-duty vehicle applications, AC is the preferred technology, while for light-duty vehicles, PM seems to have an edge thus far. The 50 to 150 kW range is effectively where the cross-over might be for switching from one technology to the other.

Existing research: HEVT [?].

- *[Summaries of existing research pending]*

Key research questions:

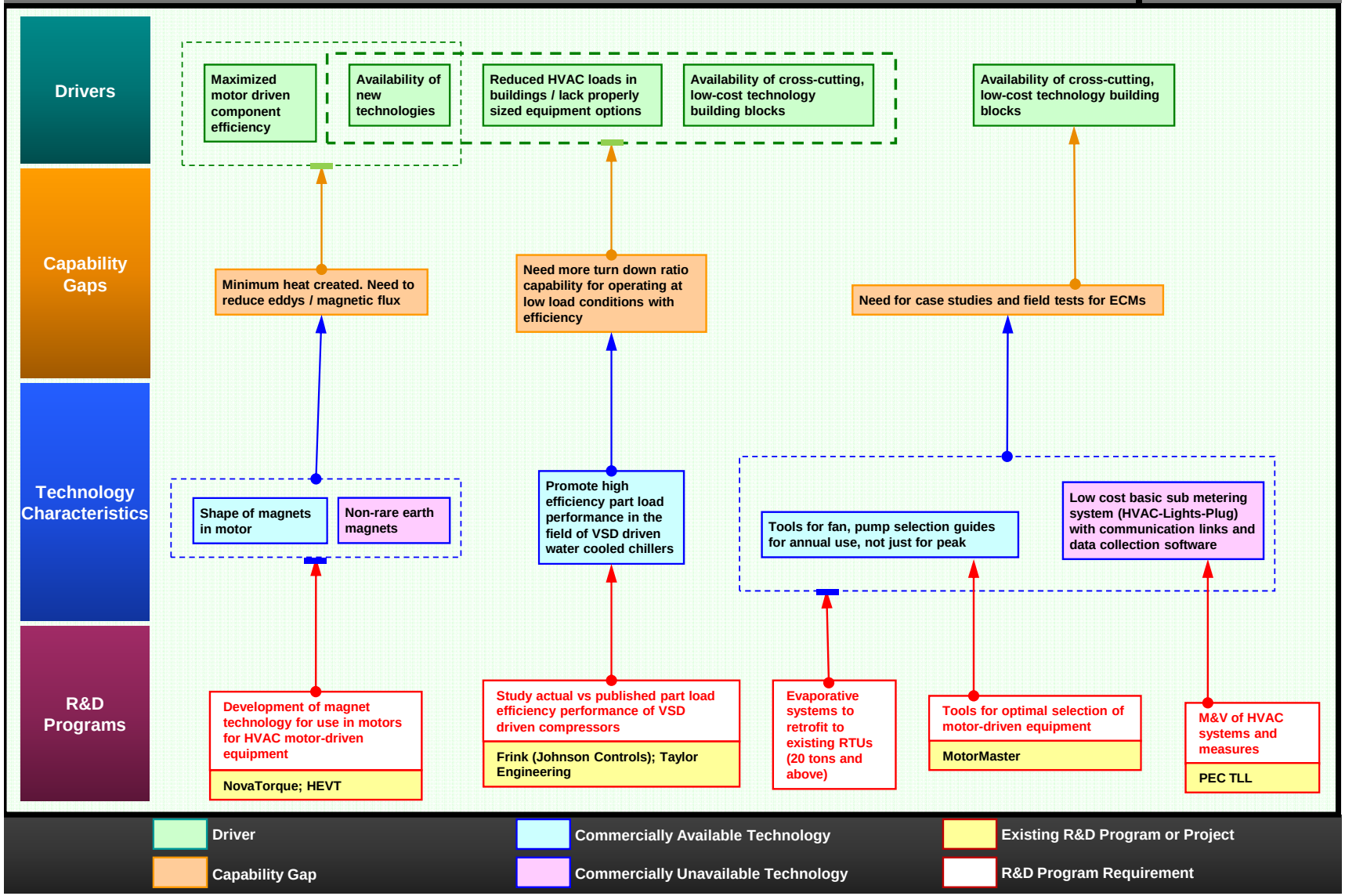
1. What are the benefits of ECMs compared to variable frequency drive (VFD) for larger motors?
2. What size does this make sense?
3. What are the cost/technology barriers to making larger ECMs?
4. How does efficiency of ECM motor compare to that of conventional motor at each motor size?
5. What is the potential market for larger ECM motors? What products will it displace and what are impacts?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **HVAC Motor-driven Systems (2 of 2)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Development of magnet technology for use in motors for HVAC motor-driven equipment. With limitations on availability of rare earth magnets, viable alternatives need to be identified and developed which are not of free earth materials and may be configured in different shapes.

Existing research: NovaTorque, HEVT.

- *[Summaries of existing research pending]*

Key research questions:

1. What research has been done / underway with regards to alternate magnet materials?
2. What materials have promise of being used are R.E replacement?
3. Is it cost effective to produce industrial-capable magnets of alternative materials?
4. What other magnet shapes provide more / optimal efficiency for motors?

Study actual vs published part load efficiency performance of VSD driven compressors. Measure output and kW of variable-speed drive (VSD) driven chillers down to 25% full capacity in field tests. Many are operating at higher kW than expected. Figure out why and recommend corrections to problems.

Existing research: Frink (Johnson Controls), Taylor Engineering.

- Frink (Johnson Controls): refrigeration compressors.
- Taylor Engineering: central chillers.
- *[Summaries of existing research pending]*

Key research questions:

1. What is the difference between published and actual field part load performance of variable frequency drive (VFD) driven chillers at 25% load?
2. How does condenser water temperature affect outcome?
3. What load modulation mechanism (e.g. hot gas bypass) is in use at 25%? What is VSD speed?
4. Why do manufacturers not publish VFD speeds at 25/50/75/100% load in published integrated part load value (IPLV) ratings?
5. Is optimization of chiller performance at 25% consistent with how system kW/ton? If not, whats the best strategy?

Continued . . .

Tools for optimal selection of motor-driven equipment. To prevent over-sizing motor driven equipment and allow them to operate at a maximum efficiency, information such as; system load profiles are required to choose the optimal number of and optimally-sized components. Tools to take this information from simulation or modeling tools and transfer them to equipment sizing tools will help engineers design better (efficient) systems.

Existing research: MotorMaster.

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- *[Summaries of existing research pending]*

Key research questions:

1. What are the current processes that design engineers use to design HVAC systems?
2. What simulation and modeling tools are used to design HVAC systems?
3. Is load profile information available from this process in terms required to size equipment?
4. What equipment selection tools exist? What inputs are required for selection?
5. Can a tool be developed to transfer system design information to a format acceptable to equipment selection tools?

M&V of HVAC systems and measures. Assess actual energy use vs predicted for various energy conservation measures and whole buildings.

Existing research: Pacific Energy Center (PEC) Tool Lending Library (TLL).

- PEC TLL: http://www.pge.com/pec/tll/.
- *[Summaries of existing research pending]*

Key research questions:

1. How do individual measures perform compared to predictions?
2. What are interaction between measures and impact on whole building energy use?
3. How does whole building energy use compare to projections?
4. Can plug and play sub metering systems be developed that will communicate via internet with data storage and analysis capability standardized?
5. What is a standardized approach to “truing up” a building simulation model to actual building energy use?
6. How should building electrical systems be designed to lower the cost of sub metering?

Evaporative systems to retrofit to existing RTUs (20 tons and above). It is time to move add-on evaporative systems to coordinated deployment. Utility field tests demonstrate energy and peak savings 10 to 40 percent.

Existing research: None identified.

Key research questions:

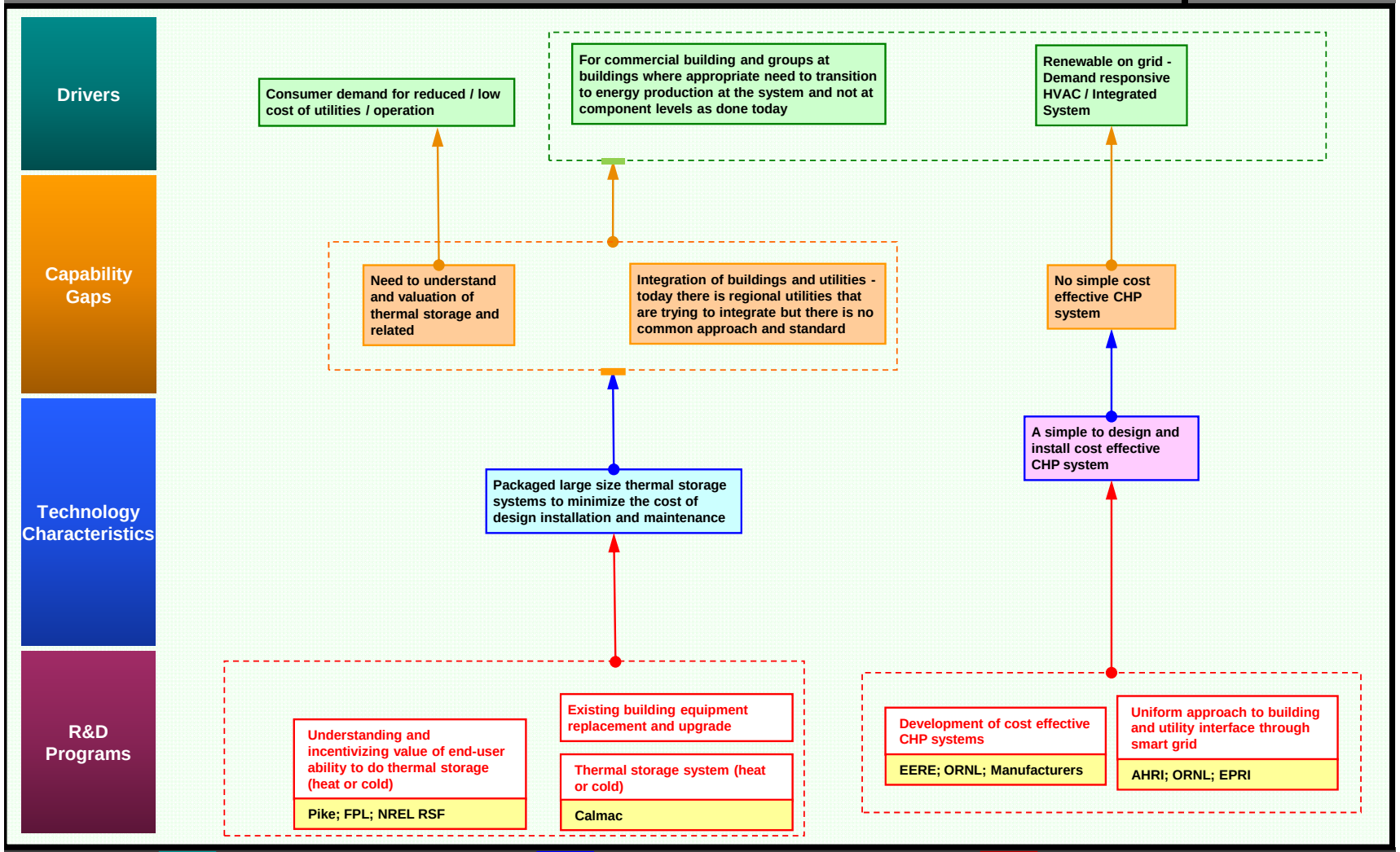
1. Can adequate fault detection be added to add-on evaporative systems to ensure sustained performance?
2. Can mechanical industry be trained and compensated at reasonable / cost effective levels to install and provide continuous commissioning?
3. Will commercial customers beyond data centers embrace this technology?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Commercial Integrated Buildings (1 of 5)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Thermal storage system (heat or cold). Continue to develop cost effective packaged thermal storage systems that can be installed in the field with minimal design cost and simple to install and operate. This shall include tools for designing and installation.

Existing research: Calmac.

- *[Summaries of existing research pending]*

Key research questions:

1. Can the current materials (phase - change) accommodate to achieve the goals?

Uniform approach to building and utility interface through smart grid. (Summary not yet provided.)

Existing research: Air-Conditioning, Heating, and Refrigeration Institute (AHRI), Oak Ridge National Laboratory (ORNL), Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

1. Develop standard and protocols to allow interface.
2. Define what should be controlled and how.
3. Define hardware and logistic.

Understanding and incentivizing value of end-user ability to do thermal storage (heat or cold). Thermal storage could shave peaks, level loads, and even provide ancillary services. The value is both location and time dependent, and hugely variable in size. We need tools that help design programs based on value, programs could range from purchase incentives through tariff provisions.

Existing research: Pike; Florida Power & Light Company (FPL); National Renewable Energy Laboratory (NREL) Research Support Facility (RSF).

- *[Summaries of existing research pending]*

Key research questions:

1. What are optimum strategies, and how do we decide when we are near enough?
2. What services would add robustness or flexibility to the grid, and what is that worth for a given utility in a specific location?
3. How do we acquire these grid resources?
4. What do equipment manufacturers have to do to respond to these utility requirements?

Continued . . .

Development of cost effective CHP systems. Work with major manufacturers on developing low-cost combined heat and power (CHP) systems using waste heat, gas, etc.

Existing research: U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE), Oak Ridge National Laboratory (ORNL), and manufacturers including Caterpillar, Ice-Bean.

- See also the CHP technology roadmpaps in this portfolio.
- *[Summaries of existing research pending]*

Key research questions:

1. Can CHP become a standard in commercial buildings?

Existing building equipment replacement and upgrade. Quantify the potential for existing building energy savings and implement programs to encourage building upgrades and equipment replacements.

Existing research: None identified.

Key research questions:

1. How much energy can be saved?
2. Address the issues of refrigerants and how to replace old R22 and RLL [?] systems?
3. Address how local codes will handle new ZL refrigerant and end use of natural refrigerants?
4. Develop procedures and incentives for energy audits and building recomissioning

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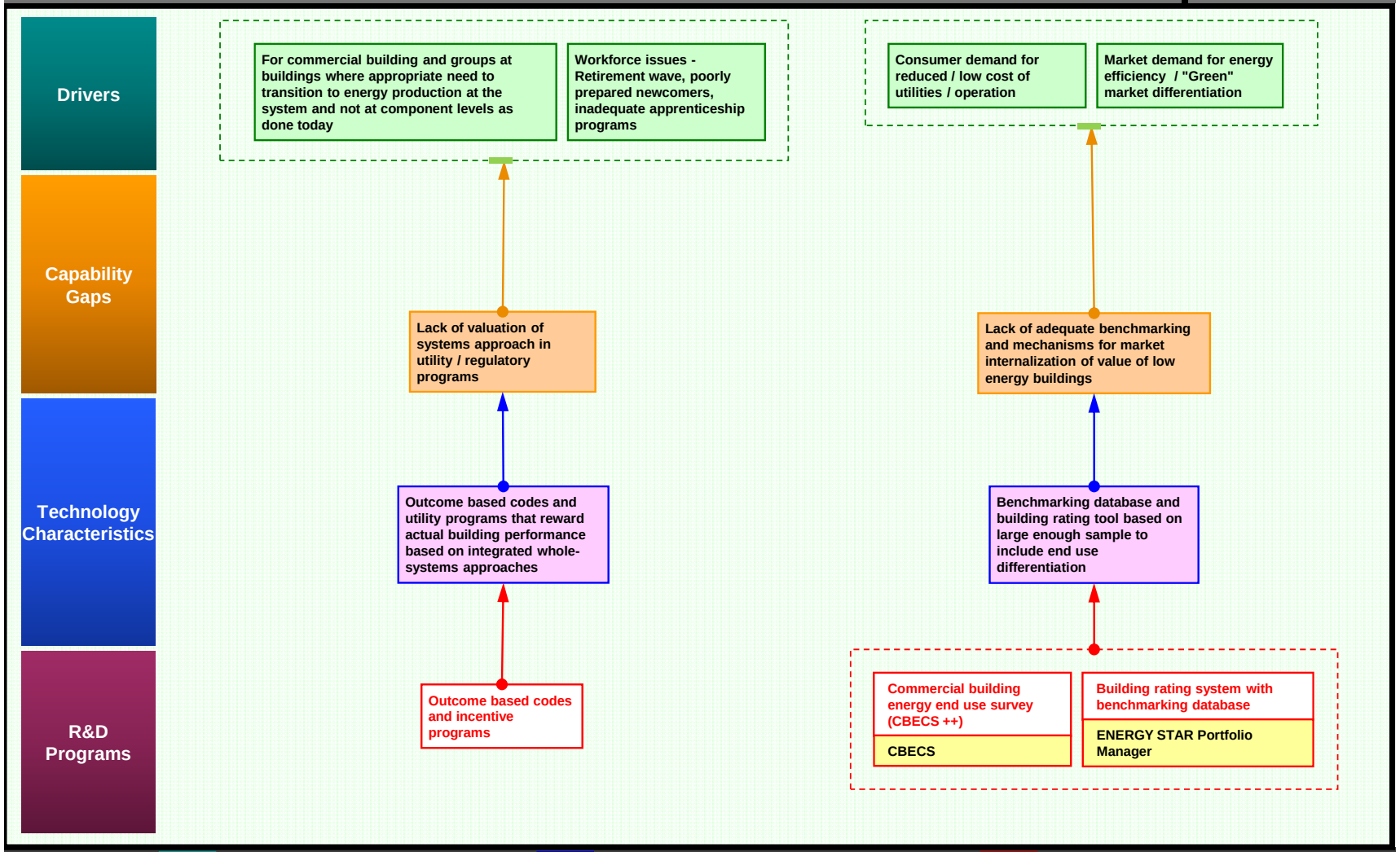
Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Commercial Integrated Buildings (2 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Building rating system with benchmarking database. Research and assess building rating systems worldwide. Develop recommendations for US building rating system. Develop proposed database for benchmarking purposes.

Existing research: ENERGY STAR Portfolio Manager.

- *[Summaries of existing research pending]*

Key research questions:

1. What countries have best-in-class building rating systems?
2. What are characteristics of best-in-class rating systems?
3. How can building rating systems best be utilized to achieve benchmarking capability?
4. How can building rating system best internalize the value of energy efficiency, demand response capabilities, and ancillary service capability into the market value of a building and its rent levels earned by the owner?

Commercial building energy end use survey (CBECS ++). Wide sample of commercial building energy use characteristics adequate to establish statistically significant benchmarks for broad sector of existing commercial building types. Include energy end use splits covering primary areas of building energy use (HVAC, lighting, hot water, server, work areas, plugs, key process energy end uses).

Existing research: CBECS.

- *[Summaries of existing research pending]*

Key research questions:

1. What is the distribution of energy use within primary commercial building usage types?
2. What is the distribution of energy use within the primary energy end use in commercial buildings?
3. What are the primary energy end use categories in commercial buildings that are important to quantify?

Outcome-based codes and incentive programs. Investigate barriers and mechanisms for implementing programs to incentivize whole building approaches that deliver low energy buildings. Develop programs to incentivize low energy buildings as opposed to efficient equipment.

Existing research: None identified.

Key research questions:

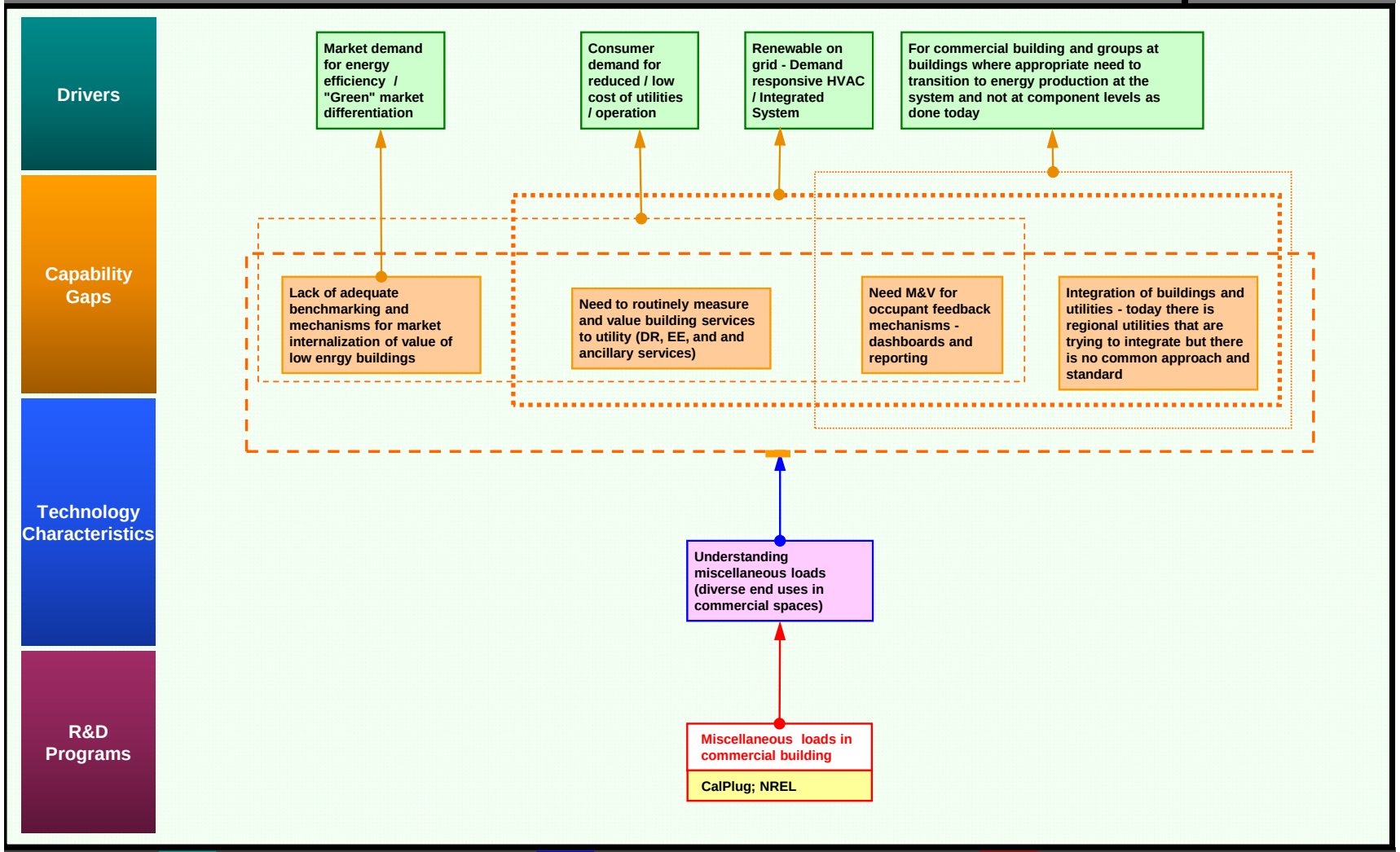
1. What are the primary benefits to programs based on actual energy end use (based on billed results)?
2. What sorts of drivers and barriers would be acceptable to market to enforce performance based programs?
3. What EVI [?] targets would be achievable and valuable enough to make this approach worthwhile?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Commercial Integrated Buildings (3 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Miscellaneous loads in commercial buildings. CBECS is bill-and model-based, but projects even lower plausibility of estimates of "miscellaneous" loads that may reach 1/3 of overall use by 2035. Must launch large, detailed end use surveys.

Existing research: California Plug Load Research Center (CalPlug); National Renewable Energy Laboratory (NREL).

- *[Summaries of existing research pending]*

Key research questions:

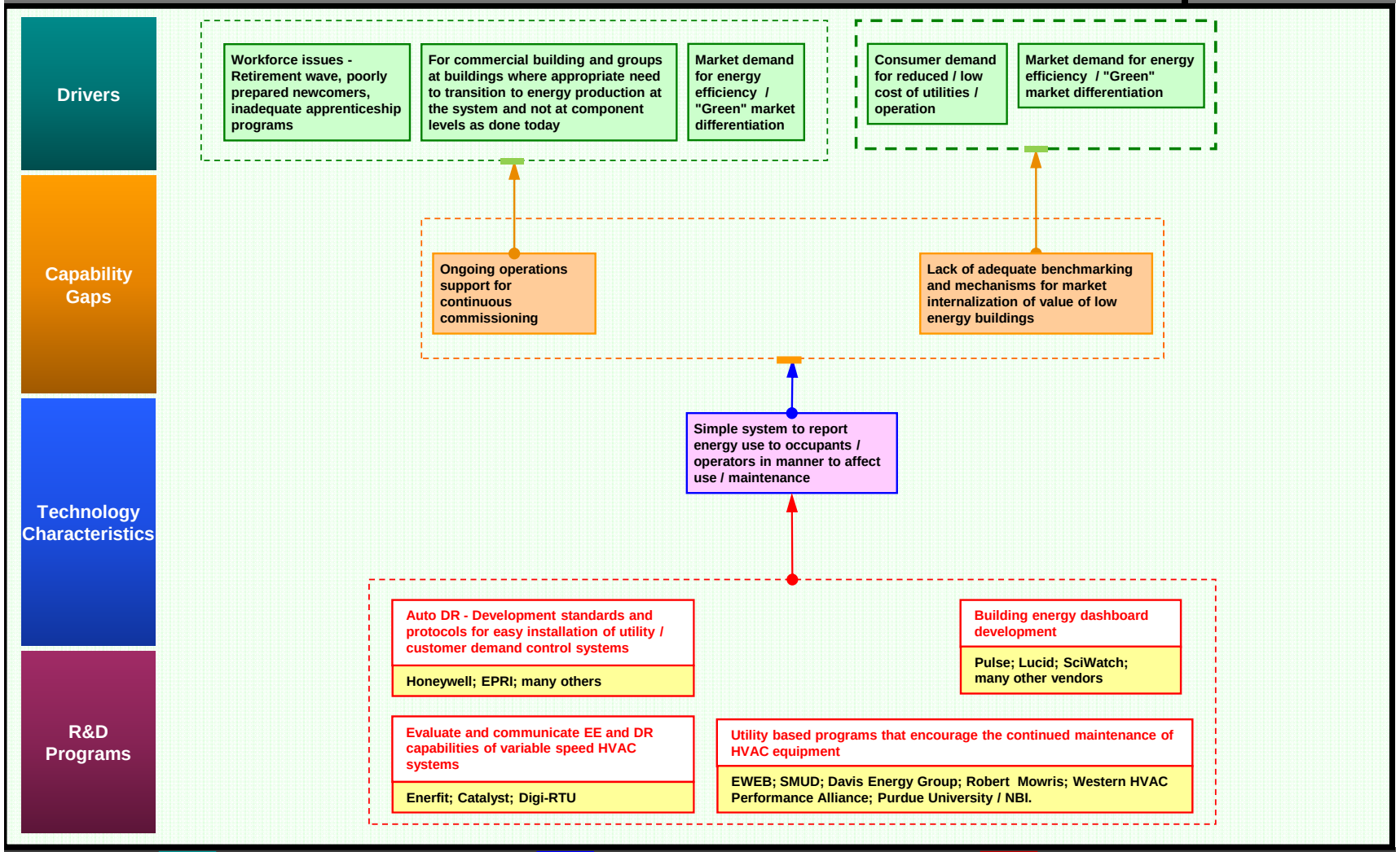
1. How to structure a 'census' of end uses by building size, use, etc.?
2. How to cost-effectively learn actual energy use dimensions in a large enough sample?
3. How to project future trajectories by end use?
4. How to do interventions to meet owner, user, and utility needs?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Commercial Integrated Buildings (4 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Auto DR - Development standards and protocols for easy installation of utility / customer demand control systems. At present, there are many different types of energy management systems. These systems are not designed for taking utility rates in real-time and control the loads to reduce peak demand (i.e., demand response (DR)). Development of standards and protocols are needed.

Existing research: Honeywell, Electric Power Research Institute (EPRI), and many others.

- *[Summaries of existing research pending]*

Key research questions:

1. How can we link grid with commercial building management systems to implement DR programs to handle peak demands, renewable, etc.?
2. What kind of software tools are needed for ease of installation, quantification of benefits, etc?
3. What kind of education and training is needed?

Utility based programs that encourage the continued maintenance of HVAC equipment. Incentive for building owners/operators to "retro commission" or have continuous HVAC maintenance. This will allow energy savings to be "real" for the life of the equipment.

Existing research: Eugene Water and Electric Board (EWEB), Sacramento Municipal Utility District (SMUD), Robert Mowris, Western HVAC Performance Alliance, Purdue University, New Buildings Institute (NBI).

- *[Summaries of existing research pending]*

Key research questions:

1. What kind of incentives will encourage building owners/operators to maintain the HVAC equipment?
2. Is there a way to make this "easy" and "cost effective"?

Building energy dashboard development. Development and research of dashboard system that can deliver information to building occupants and operators in actionable format

Existing research: Pulse, Lucid, SciWatch, and many other vendors.

- *[Summaries of existing research pending]*

Key research questions:

1. What pieces of information to occupants/operators need in order to alter their behavior and deliver true energy savings?
2. What is the best way to present this information in order to achieve greatest attention?
3. What are implications of dashboard requirements or building system, electrical, control system design?

Evaluate and communicate EE and DR capabilities of variable speed HVAC systems. Study EE and demand response (DR) capabilities of variable speed rooftop and chiller HVAC systems. Quantify energy savings and peak load reduction capabilities of variable speed HVAC equipment compared to fixed speed systems. Determine economic values to utilities.

Existing research: Enerfit, Catalyst, DigiRTU.

- *[Summaries of existing research pending]*

Key research questions:

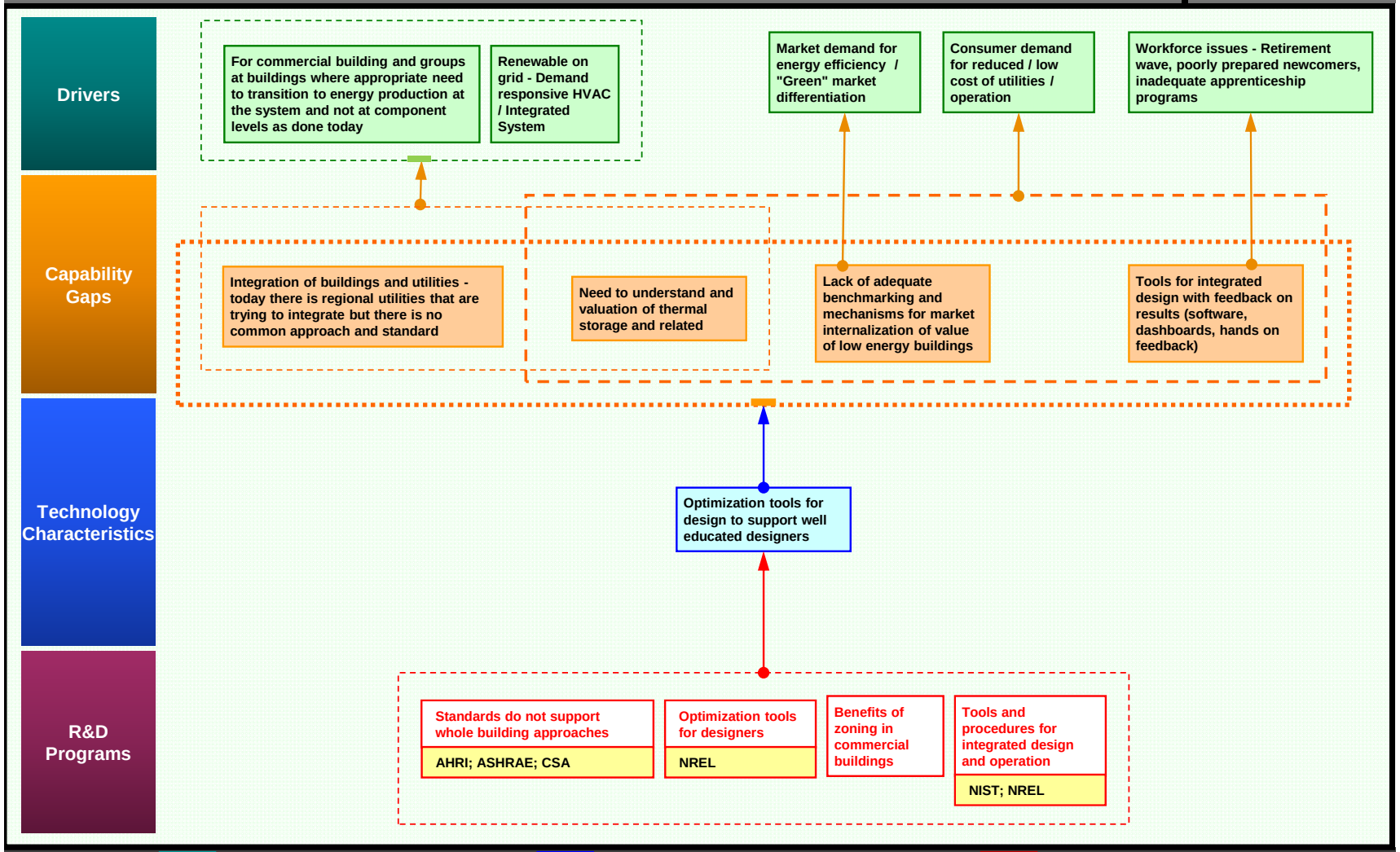
1. What are the full year energy savings profiles of variable speed systems compared to fixed speed systems?
2. How much reduction in cooling output is required to produce a given power input reduction?
3. How should utility DR programs be structured to best utilize the capability of variable speed equipment, for example variable speed reduction or thermostat setback. How to optimize?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Commercial Integrated Buildings (5 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Standards do not support whole building approaches. Current standards as well as incentive programs are focused on single metric and prescriptive approaches.

Existing research: Air-Conditioning, Heating, and Refrigeration Institute (AHRI), American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), CSA International.

- *[Summaries of existing research pending]*

Key research questions:

1. Evaluate and consider some of the whole building systems.
2. Change incentive programs to consider hybrid systems and building level metric.
3. Develop new rating metrics for equipment to support systems analysis.
4. New simplified user friendly tools to support whole building approach.

Optimization tools for designers. Assume a design team and a project. How do we provide optimization tools that allow rapid screening of system options (shell and systems) with sensitivities?

Existing research: National Renewable Energy Laboratory (NREL).

- *[Summaries of existing research pending]*

Key research questions:

1. How do we get private sector to value doing this?
2. What are the tool specifications?
3. How do we qualify designers?
4. How do we acquire the resource?

Benefits of zoning in commercial buildings. There is disagreement within the industry regarding the energy and other benefits of zoned systems compared to large central systems. Meter existing buildings with ductless VRF + DOAS compared to central VAV systems, or other central systems. Isolate benefits of zoning.

Existing research: None identified.

Key research questions:

1. Does improved comfort and control lead to increases in energy use?
2. Does loss of easy implementation of economizers offset gains from fan energy savings?
3. Are there some conditions where more highly zoned systems use more energy than central systems?

Tools and procedures for integrated design and operation. Develop, test, demonstrate and deploy simulation tools and interfaces that can be used in the different stages of design and in commissioning retrofit and routine operation to maximize energy efficiency at each stage in the life cycle.

Existing research: National Institute of Standards and Technology (NIST), National Renewable Energy Laboratory (NREL).

- NREL: See Appendix B.
- NIST: See Appendix B.

Key research questions:

1. Define use cases, work flow and information at each stage.
2. Identify, extend and validate suitable simulation tools.
3. Develop efficient methods of construction models of existing buildings.
4. Develop software and hardware architectures and specifications for integrating simulation and measures performance.

R&D Program Summaries

Other R&D Project Summaries generated at the Sep. 2012 National Energy Efficiency Technology Roadmapping Summit not included in Commercial Integrated Building roadmaps in previous pages . . .

Valuing non-energy benefits. Utility incentive programs take a narrow cost-benefit approach looking only at kW and kWh. Customers assign real value to comfort, lack of glare, and drafts, and offer amenity. We need to understand what they value, how much, and how to use their payments for these services in programs?

Existing research: American Council for an Energy-Efficient Economy (ACEEE), Behavior, Energy, and Climate Change (BECC).

- *[Summaries of existing research pending]*

Key research questions:

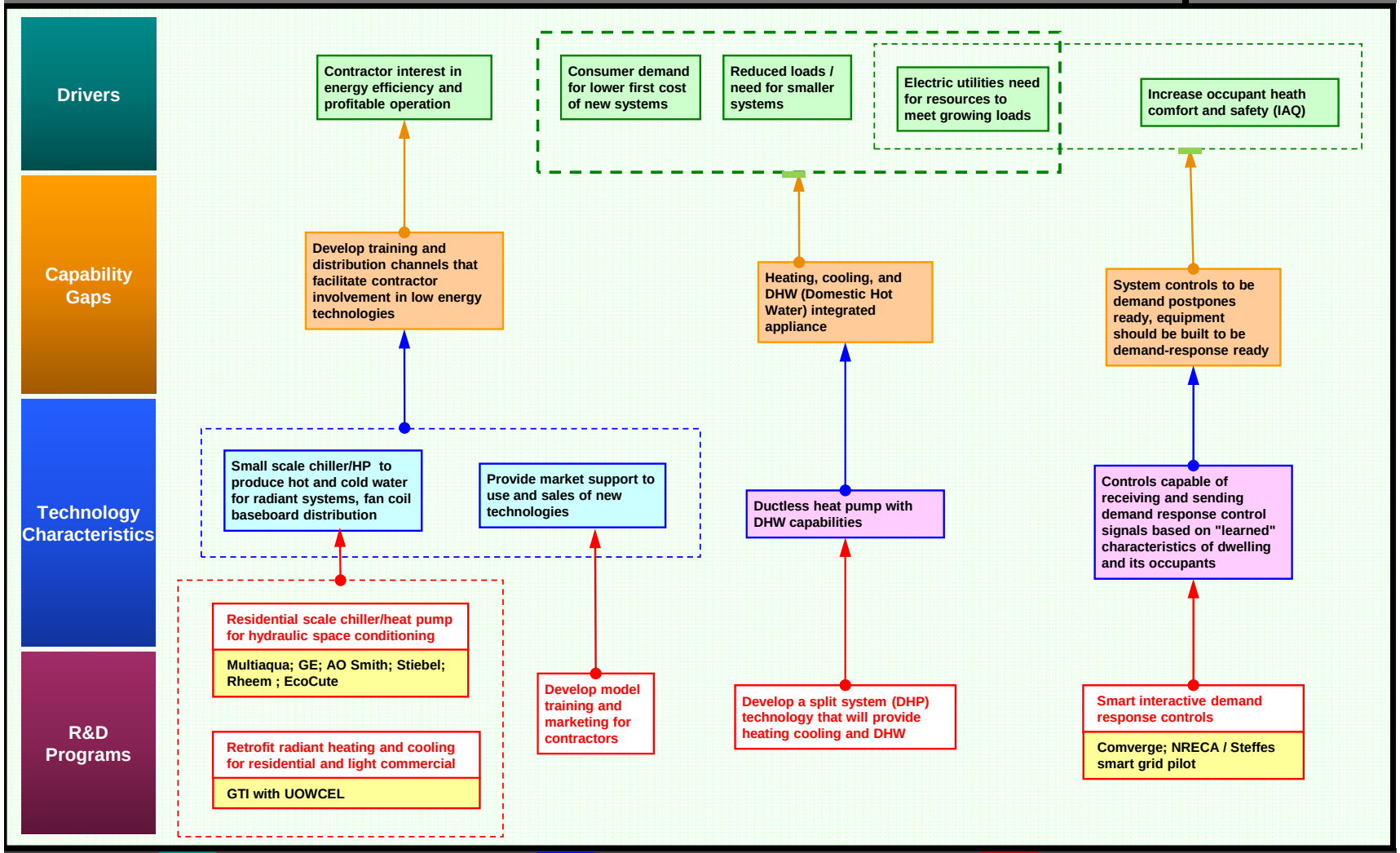
1. What 'amenities' (including reliability) do customers value, and how much?
2. What is 'fair' to ratepayers in accommodating these customer-paid costs in program evaluation?
3. How do we explain these to stakeholders?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Residential HVAC (1 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Retrofit radiant heating and cooling for residential and light commercial. Purpose: develop generic performance specification for radiant heating and cooling systems. Scope: Residential and light commercial new and existing buildings HAVC. Goals: Method of testing radiant, hydronic system/panels. Best practices for design and installation of retrofit radiant systems.

Existing research: Gas Technology Institute (GTI) with UOWCEL [?] .

- *[Summaries of existing research pending]*

Key research questions:

1. What testing methods is needed to provide designers, manufactures, energy efficiency programs, contractors, and owner's information needed to make decisions?
2. What material(s) spread the thermal energy between fluid tubing optimally for each of the generic system configurations?
3. What is the moisture control required in radiant cooling dwellings by climate zone and occupancy scenario?
4. What controls are needed for radiant since the standard room thermostat is not optimal?
5. What is the optimal for comfort control strategy?
6. What is the optimal demand reduction strategy and in a related matter what level of thermal mass storage is needed?

Residential scale chiller/heat pump for hydronic space conditioning. Purpose: Develop test standard for residential code chiller/heat pump. Explore the viability and best practices for field conversion of condensers to chillers. Scope: 65K<, single phase air source condensers used to chill and heat water. Goal: Make available in the market place equipment that supports.

Existing research: Multiaqua, HPWHs by GE, AO Smith, Stiebel, Rheem, EcoCute.

- *[Summaries of existing research pending]*

Key research questions:

1. How shell 65K, single phase chillers/heat pumps is rated and certified?
2. Can a field installed refrigerant to water heat exchanger achieve OEM chiller/heat pump efficiency and reliability?
3. What are the best practices for field installed conversions?
4. What is the design for a cost effective storage tank to move chiller operation off peak?
5. What does it take to add domestic hot water to equipment?

Continued . . .

Smart interactive demand response controls. Purpose: generic specification for interactive smart demand response controls for residential HVAC systems. Scope: Residential dwellings. Goals: Market place functional specification for smart demand response controls.

Existing research: Comverge; National Rural Electric Cooperative Association (NRCA) / Steffes smart grid pilot.

- *[Summaries of existing research pending]*

Key research questions:

1. Under what scenarios can turning "on" customer's cooling system reduce or eliminate peak demand?
2. What is the optimal building thermal mess for eliminating peak time compressor operation with and without right ventilation cooling?

Develop a split system (DHP) technology that will provide heating cooling and DHW. Identify temperature delivery equipment for each load to be met. Provide distribution for heat and cooling. Provide Hx for refrigerant to domestic hot water (DHW).

Existing research: None identified.

Key research questions:

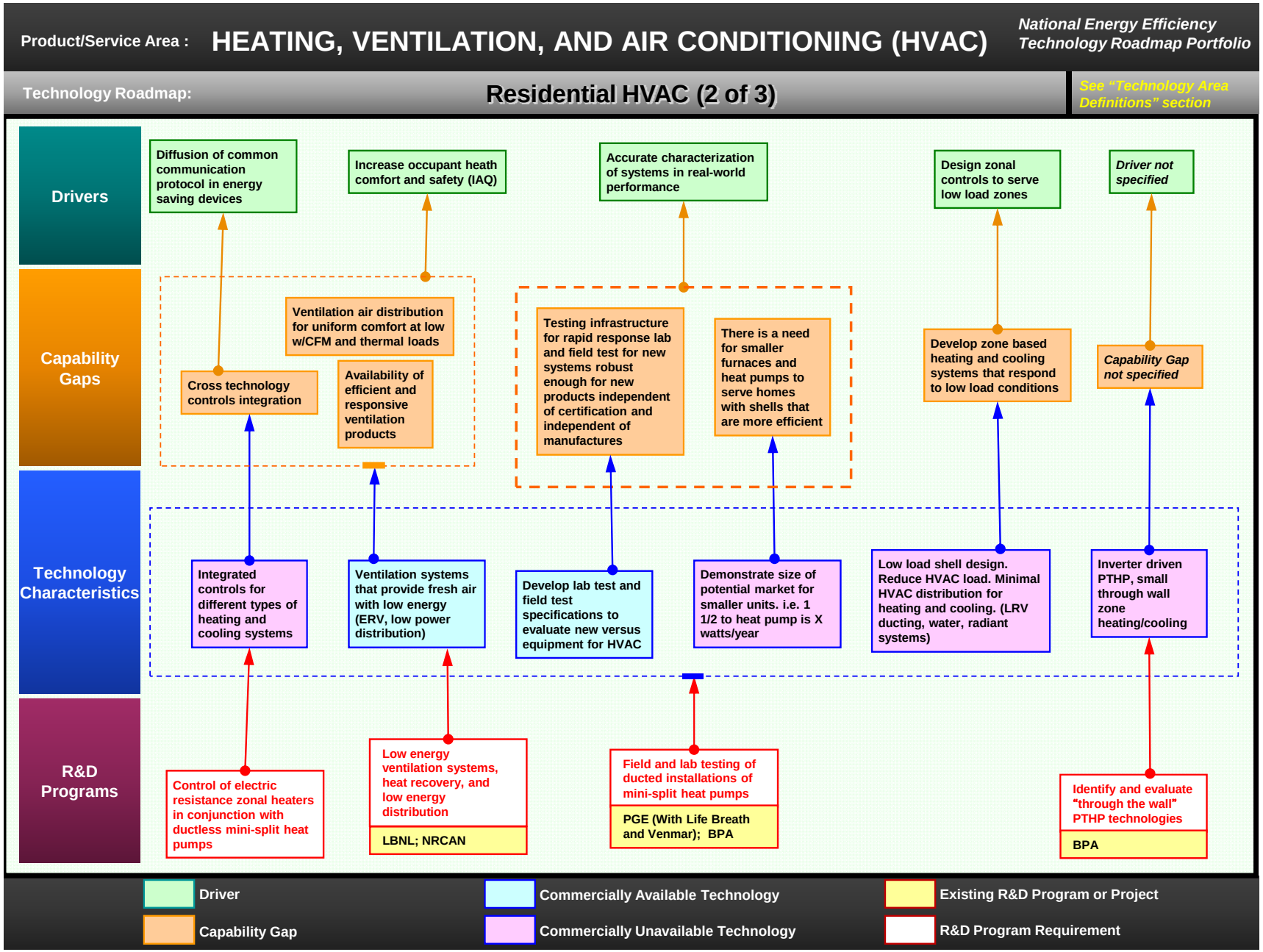
1. Can conventional refrigerants provide the range of temperatures?
2. Do costs allow this integration?
3. What is the effective cop's across the various delivery outputs?

Develop model training and marketing for contractors. Contractors need to understand the technologies and sales requirements of low energy systems.

Existing research: None identified.

Key research questions:

1. What are the key skills and knowledge gaps that should be addressed?
2. What business case must be made to persuade shops and HVAC installers to invest understanding the technologies?
3. Which tools are needed to support installation and testing?
4. What commission is needed with the technologies?


Product/Service Area :
HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Residential HVAC (2 of 3)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Diffusion of common communication protocol in energy saving devices
Increase occupant heath comfort and safety (IAQ)
Accurate characterization of systems in real-world performance
Design zonal controls to serve low load zones
Driver not specified
Ventilation air distribution for uniform comfort at low w/CFM and thermal loads
Cross technology controls integration
Availability of efficient and responsive ventilation products
Testing infrastructure for rapid response lab and field test for new systems robust enough for new products independent of certification and independent of manufactures
There is a need for smaller furnaces and heat pumps to serve homes with shells that are more efficient
Develop zone based heating and cooling systems that respond to low load conditions
Capability Gap not specified
Integrated controls for different types of heating and cooling systems
Ventilation systems that provide fresh air with low energy (ERV, low power distribution)
Develop lab test and field test specifications to evaluate new versus equipment for HVAC
Demonstrate size of potential market for smaller units. i.e. 1 1/2 to heat pump is X watts/year
Low load shell design. Reduce HVAC load. Minimal HVAC distribution for heating and cooling. (LRV ducting, water, radiant systems)
Inverter driven PTHP, small through wall zone heating/cooling
Control of electric resistance zonal heaters in conjunction with ductless mini-split heat pumps
Low energy ventilation systems, heat recovery, and low energy distribution
LBNL; NRCAN
Field and lab testing of ducted installations of mini-split heat pumps
PGE (With Life Breath and Venmar); BPA
Identify and evaluate "through the wall" PTHP technologies
BPA
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Low energy ventilation systems, heat recovery, and low energy distribution. Establish metrics for IAQ assessment and measurement. Track IAQ needs across home. Provide reference to national standards. Implement ventilation systems (ducted ERV, integrated with HVAC distribution, point source ventilation).

Existing research: Lawrence Berkeley National Laboratory (LBNL), Natural Resources Canada (NRCAN).

- LBNL: pollution and envelope tightness.
- *[Summaries of existing research pending]*

Key research questions:

1. Can adequate IAQ be maintained with point ventilation?
2. Do fan power ventilation systems provide net energy efficiency with and without heat recovery or can ventilation systems provide all of the home's distribution system?

Field and lab testing of ducted installations of mini-split heat pumps. Mini split heat pumps with wall hung indoor heads has been evaluated. Ducted application, while popular, has lower HSPF and SEER ratings. What are the real performance and energy efficiency application of those systems?.

Existing research: PGE working with life breath and venmar; Bonneville Power Administration (BPA).

- *[Summaries of existing research pending]*

Key research questions:

1. What is the tested and monitored performance of ducted mini splits? How the compare to wall do hung units?
2. Are there limitations or installation issues that result in loss of performance and low energy savings?
3. What types of ducted invented driven mini-split heats are available?

Identify and evaluate "through the wall" PTHP technologies. Develop systems that meet needs of individual zones matched to low load in these zones.

Existing research: BPA.

- *[Summaries of existing research pending]*

Key research questions:

1. Can zone heating that addresses a single zone provide temperature control for the whole house?
2. What are the load limits that would allow zone systems to provide innless at single and discontinue?
3. What level of distribution is required for what level of develop efficiency?

Continued . . .

Control of electric resistance zonal heaters in conjunction with ductless mini-split heat pumps. With the installation of ductless heat pumps (DHPs) in homes with zonal electric heat there is no control of the interaction of the two systems. Occupants do not get clear signals when the electric resistance system is operating when it is not needed (i.e. when DHP is cooling on or when DHP could handle the load if not being out powered by electric resistance).

Existing research: None identified.

Key research questions:

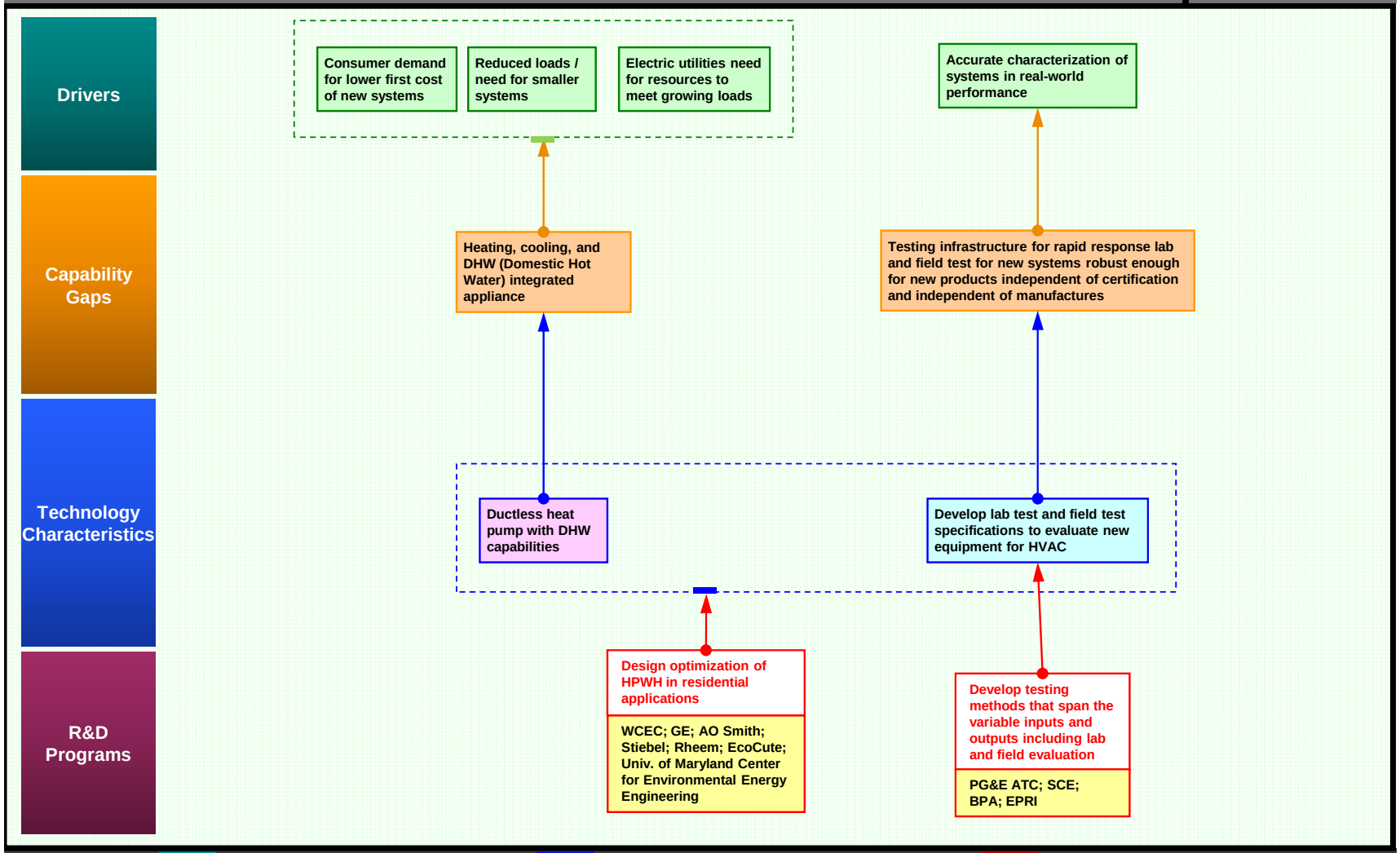
1. Are there commercial available controllers of electric resistance heaters that can communicate with other controls?
2. Are there commercial available controllers the clearly indicate when they are on and have to turn the electric resistance heat off at the controller?
3. What is the energy savings penalty when electric resistance and DHP system compete?
4. What control strategies produce the most energy saving?
5. What is technically possible?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Residential HVAC (3 of 3)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Design optimization of HPWH in residential applications. There is a wide range of variations in how to integrate heat pump water heater (HPWH) in residential sectors. The optimum design differs with heating system (electrical resistance versus ductless heat pump (DHP)), ventilation system (heat recovery ventilators (HRV) versus exhaust only), climate (heating versus cooling), and home configuration (basement, garage). Research is needed to establish a guideline for optimal design.

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC), General Electric (GE), AO Smith, Stielbel, Rheem, EcoCute, University of Maryland Center for Environmental Energy Engineering.

- *[Summaries of existing research pending]*

Key research questions:

1. When should cold air be exhausted from home?
2. When should HPWH be located inside?
3. How can we best take advantage of ventilation heat recovery? Integration with ventilation issues.

Develop testing methods that span the variable inputs and outputs including lab and field evaluation. Develop lab testing specifications that span operating temperature range fan. Develop testing specifications for varying compressor and fan speeds. Establish field testing requirements to integrate lab results and field operation.

Existing research: Pacific Gas & Electric (PG&E) ATC [?]; Southern California Edison (SCE); Bonneville Power Administration (BPA); Electric Power Research Institute (EPRI).

- *[Summaries of existing research pending]*

Key research questions:

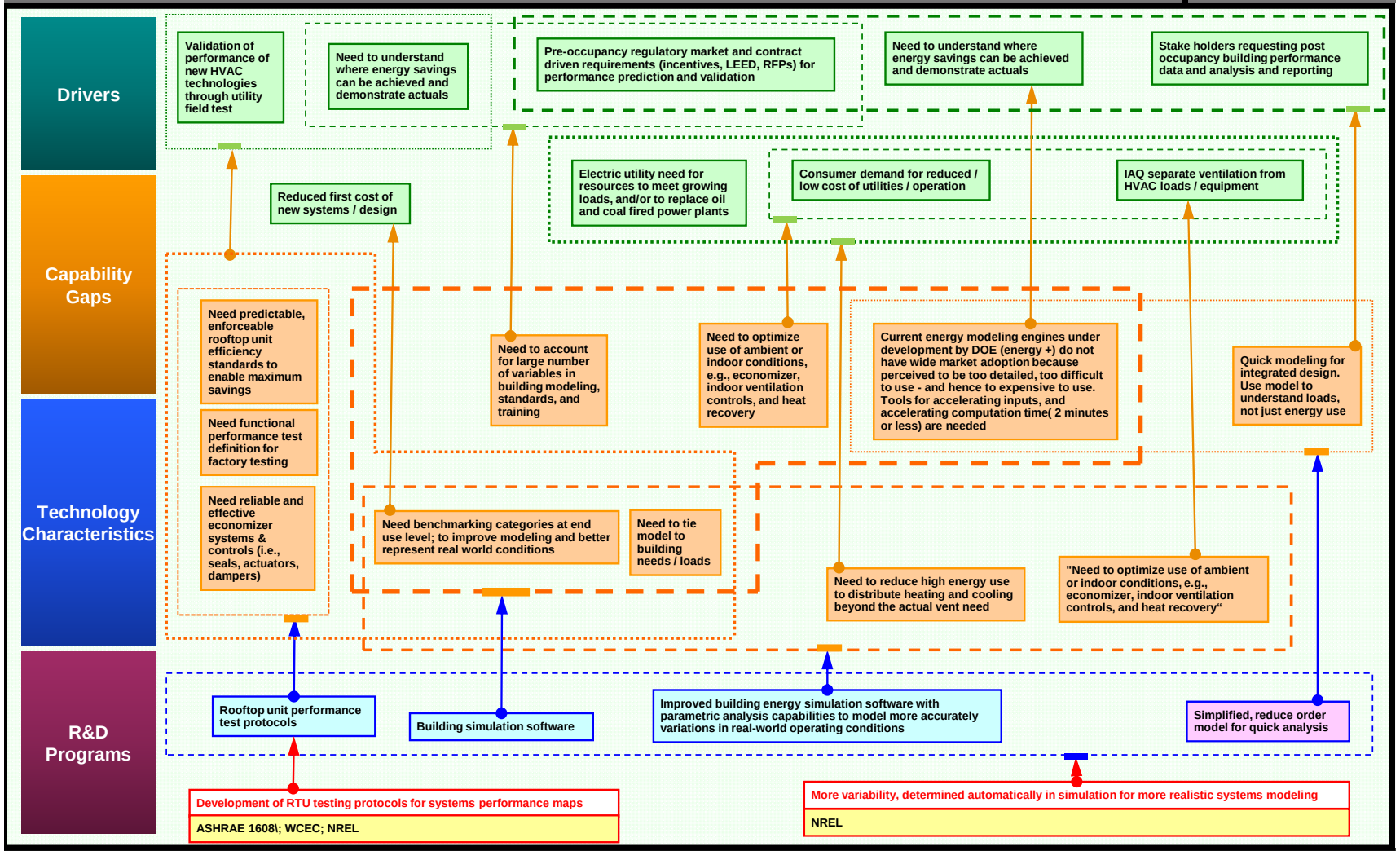
1. Can a widely varying operation speeds be summarize into usable performance metrics?
2. Once tested do observed performance verify test results?

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Modeling, Lab and Field Testing (1 of 10)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Development of RTU testing protocols for systems performance maps . The American Society of Heating, Refrigeration, and Air-Conditioning Engineers (ASHRAE) is currently working on updating the testing standard for roof-top units; ASHRAE 1608-RTAR.

Existing research: ASHRAE 1608, UC Davis WCEC, NREL.

- NREL is currently working on a Technology Performance Exchange.
- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

More variability, determined automatically in simulation for more realistic systems modeling. Building modeling for design has been a great boon to designing energy-efficient buildings, but there is much room for improvement. We need to develop the capability to program-in more variability for specific building conditions. Ideally, the program could anticipate some of the specific features. We should also make it much easier to try out alternative scenarios and perhaps have modules that would automatically suggest design optimization options.

Existing research: National Renewable Energy Laboratory (NREL).

- *[Summaries of existing research pending]*

Key research questions:

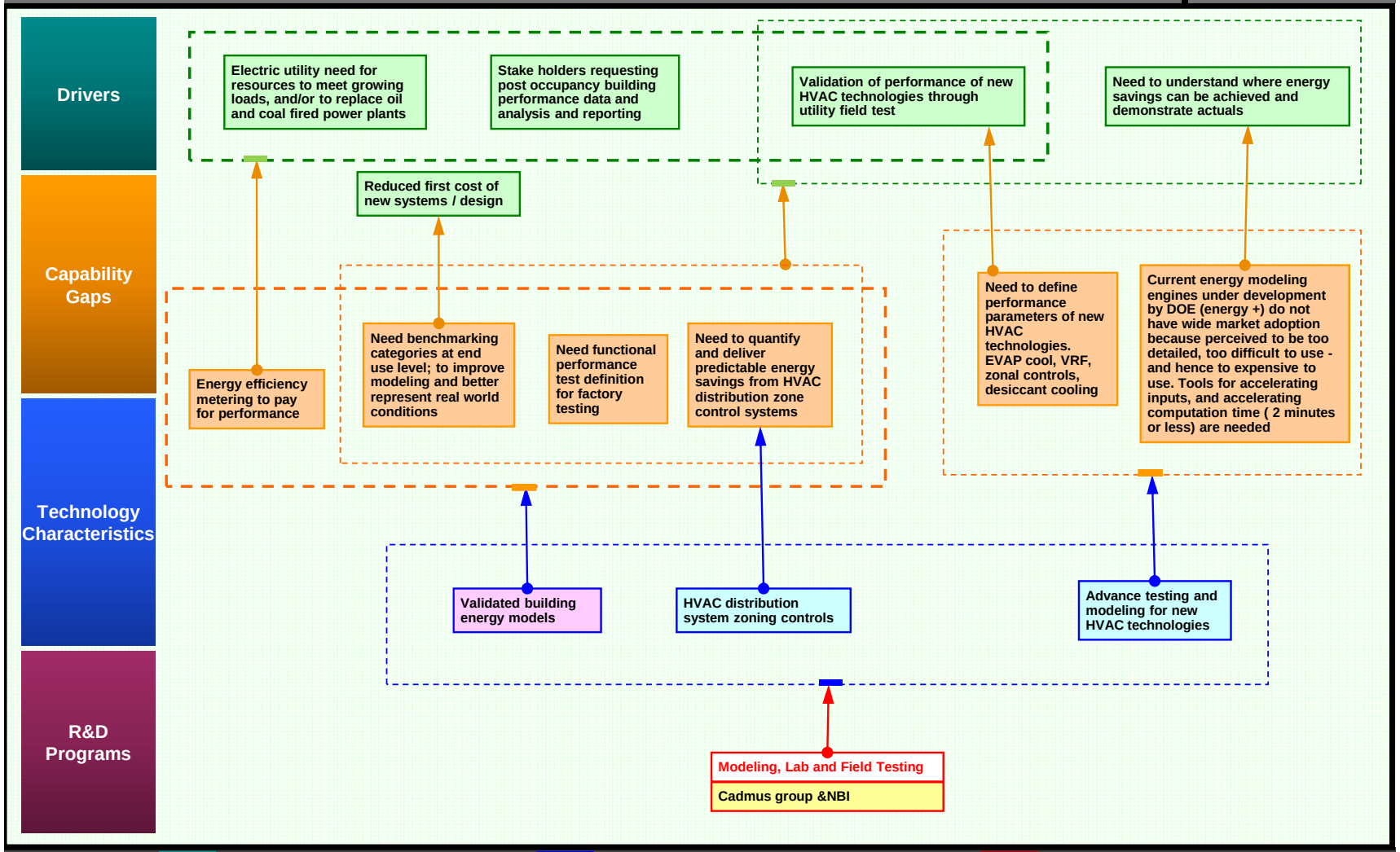
1. Questions not yet specified.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Modeling, Lab and Field Testing (2 of 10)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Modeling, lab, and field testing. (Summary not yet provided.)

Existing research: Cadmus group &New Buildings Institute (NBI).

- *[Summaries of existing research pending]*

Key research questions:

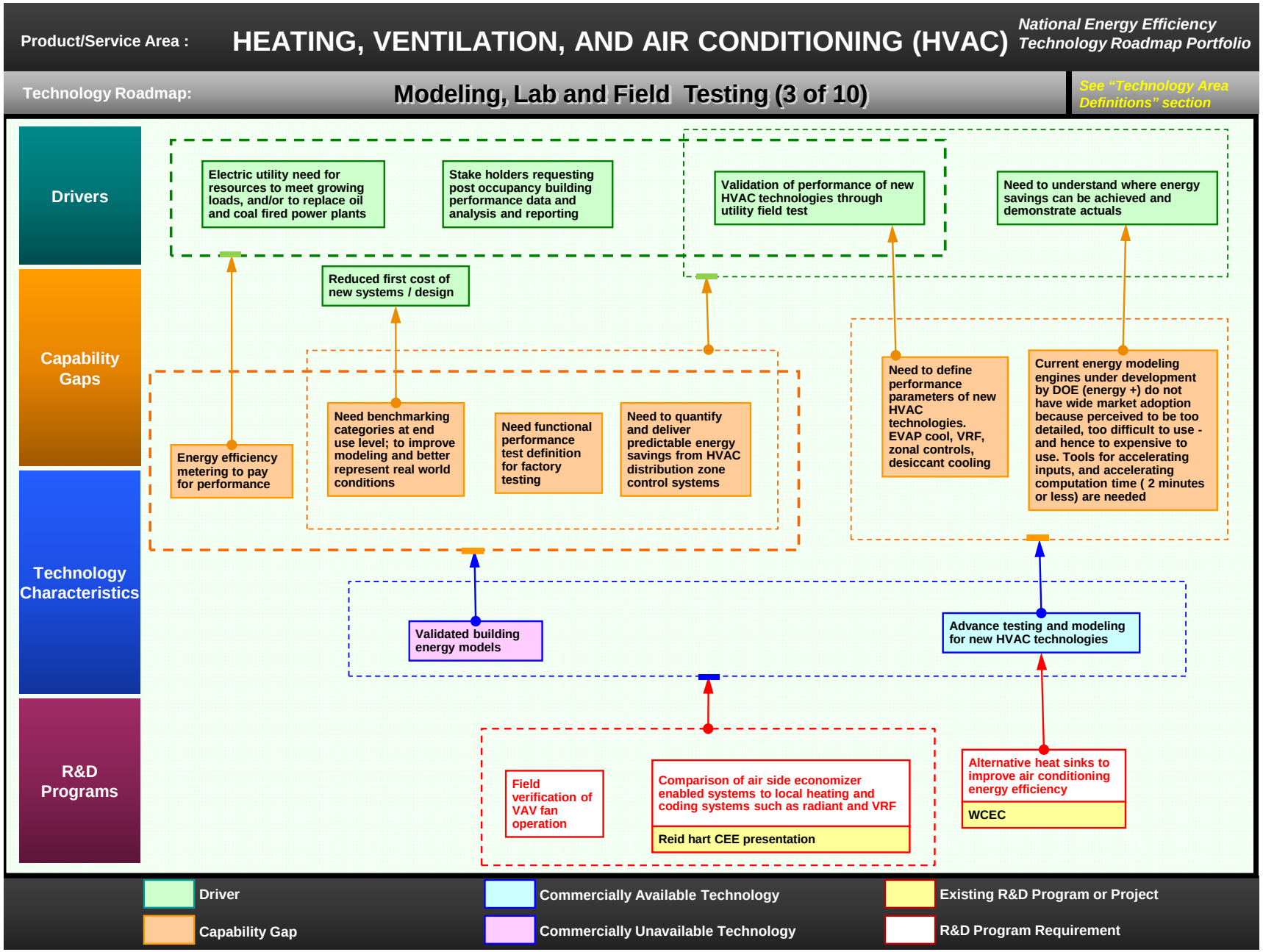
1. Questions not yet specified.

Predictive occupancy residential HVAC zone control distribution system. Significant energy savings will result from refining and tailoring occupancy controls to improve upon existing control systems.

Existing research: None identified.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Modeling, Lab and Field Testing (3 of 10)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Electric utility need for resources to meet growing loads, and/or to replace oil and coal fired power plants
Stake holders requesting post occupancy building performance data and analysis and reporting
Validation of performance of new HVAC technologies through utility field test
Need to understand where energy savings can be achieved and demonstrate actuals
Reduced first cost of new systems / design
Energy efficiency metering to pay for performance
Need benchmarking categories at end use level; to improve modeling and better represent real world conditions
Need functional performance test definition for factory testing
Need to quantify and deliver predictable energy savings from HVAC distribution zone control systems
Need to define performance parameters of new HVAC technologies. EVAP cool, VRF, zonal controls, desiccant cooling
Current energy modeling engines under development by DOE (energy +) do not have wide market adoption because perceived to be too detailed, too difficult to use - and hence to expensive to use. Tools for accelerating inputs, and accelerating computation time (2 minutes or less) are needed
Validated building energy models
Advance testing and modeling for new HVAC technologies
Field verification of VAV fan operation
Comparison of air side economizer enabled systems to local heating and coding systems such as radiant and VRF
Reid hart CEE presentation
Alternative heat sinks to improve air conditioning energy efficiency
WCEC
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Field verification of VAV fan operation . (Summary not yet provided.)

Existing research: Portland Energy Conservation, Inc. (PECI) (complete) VAV field survey protocol.

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Comparison of air side economizer enabled systems to local heating and coding systems such as radiant and VRF. (Summary not yet provided.)

Existing research: Subject matter experts reported in September 2012: "Reid Hart CEE presentation."

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Alternative heat sinks to improve air conditioning energy efficiency. (Summary not yet provided.)

Existing research: University of California Davis Western Cooling Efficiency Center (WCEC).

- *[Summaries of existing research pending]*

Key research questions:

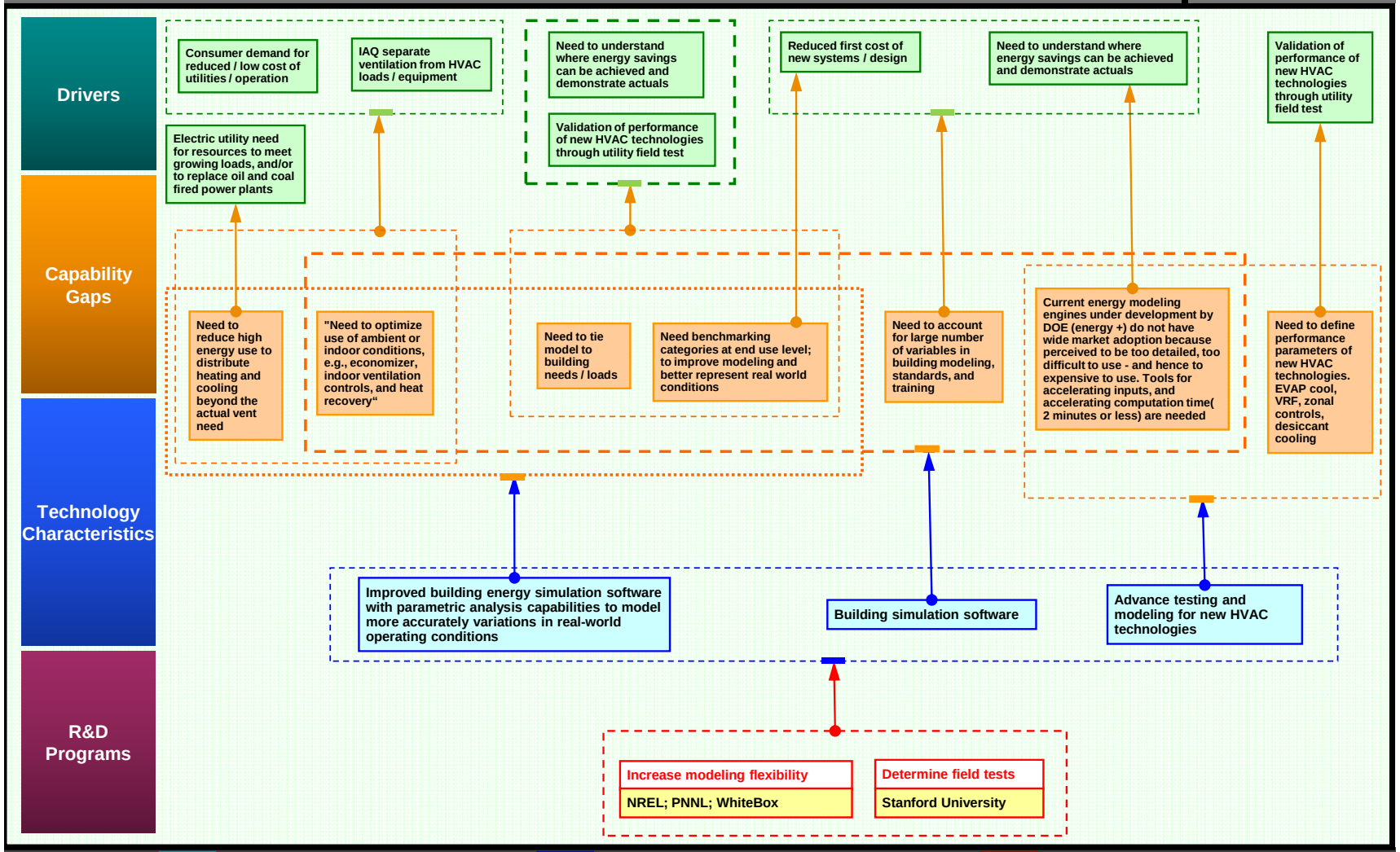
1. Questions not yet specified.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Modeling, Lab and Field Testing (4 of 10)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Determine field tests. (Summary not yet provided.)

Existing research: Sanford University.

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Increase modeling flexibility. (Summary not yet provided.)

Existing research: National Renewable Energy Laboratory (NREL); Pacific Northwest National Laboratory (PNNL); WhiteBox.

- *[Summaries of existing research pending]*

Key research questions:

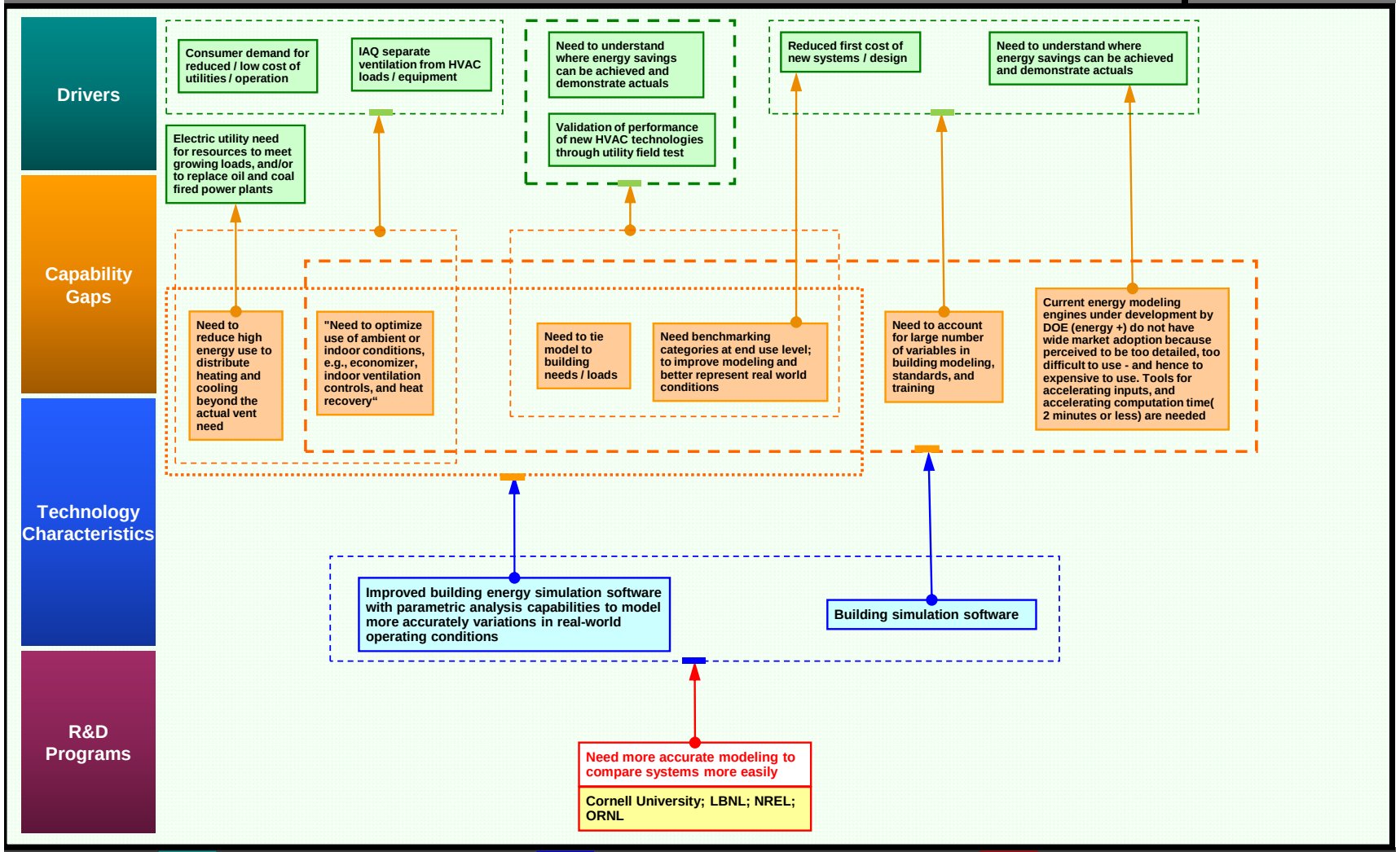
1. Questions not yet specified.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Modeling, Lab and Field Testing (5 of 10)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

Need more accurate modeling to compare systems more easily. Building modeling for design has been a great boon to designing energy-efficient buildings, but there's much room for improvement. We should make it much easier to try out alternative scenarios without having to do detailed re-designing of the building model.

Existing research: Researchers at the Lawrence Berkeley National Laboratory's (LBNL) and Cornell University are working on aspects of this, as is the Oak Ridge National Laboratory (ORNL).

- LBNL's Simulation Research Group is involved in research, development, and deployment of building design and operation software tools. Recent products that they've launched include EnergyPlus whole building simulation tool (http://apps1.eere.energy.gov/buildings/energyplus/), Building Controls Virtual Test Bed (http://simulationresearch.lbl.gov/bcvtb), and the GenOpt generic optimization program (http://simulationresearch.lbl.gov/GO/).
- The LBNL Simulation Research Group also manages the "Modelica Library for Building Energy and Control Systems," a free and expanding library of open-source dynamic simulation models for building energy and control systems (http://simulationresearch.lbl.gov/modelica). Administrators of this library seek contributions to the library's holdings, and are particularly interested, as of early 2012, in expanding the library; validating models currently in the library; enhancing documentation; and improving the numerical robustness of large system models.
- A team within the Cornell University Program of Computer Graphics is working on a three-year grant funded by the Department of Energy (using American Recovery and Reinvestment Act (ARRA) funds) to use computer building simulations to streamline green design; see Appendix B for more information.
- ORNL: See Appendix B.

Key research questions:

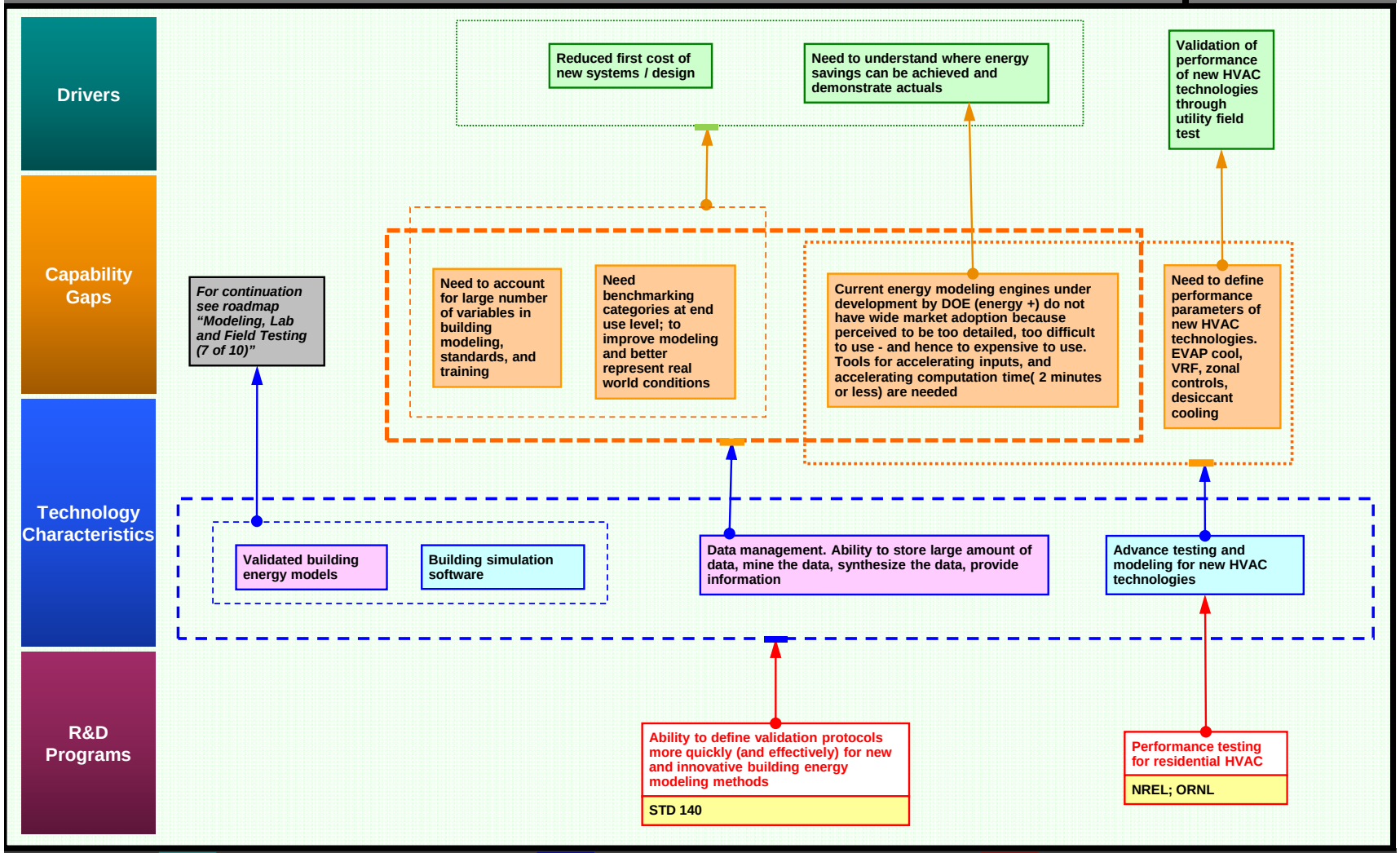
1. Questions not yet specified.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Modeling, Lab and Field Testing (6 of 10)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Ability to define validation protocols more quickly (and effectively) for new and innovative building energy modeling methods. (Summary not yet provided.)

Existing research: STD 140.

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

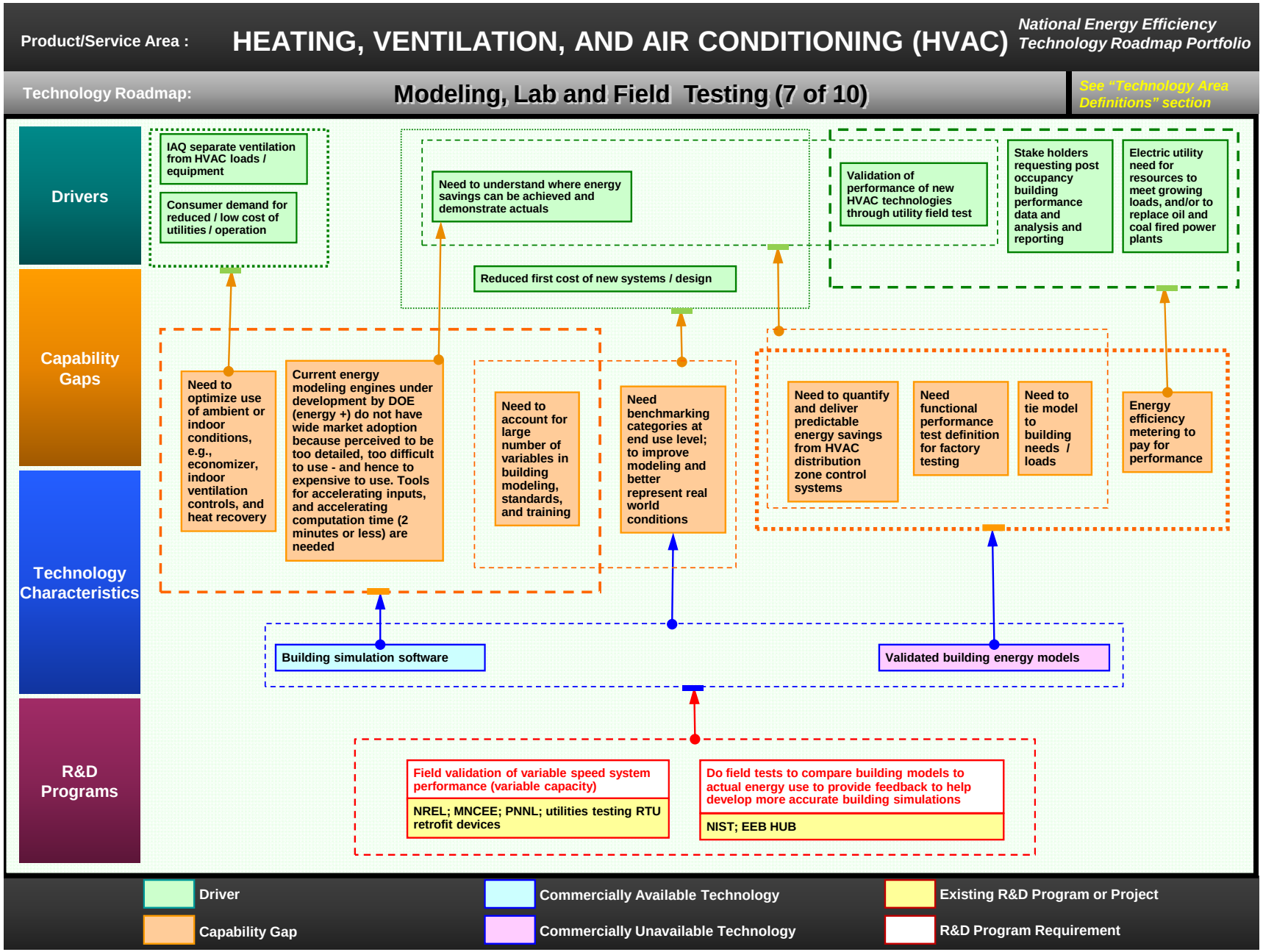
Performance testing for residential HVAC. (Summary not yet provided.)

Existing research: National Renewable Energy Laboratory (NREL), Oak Ridge National Laboratory (ORNL).

- ORNL: See Appendix B.
- NREL: See Appendix B.

Key research questions:

2. Questions not yet specified.


Product/Service Area :
HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Modeling, Lab and Field Testing (7 of 10)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
IAQ separate ventilation from HVAC loads / equipment
Consumer demand for reduced / low cost of utilities / operation
Need to understand where energy savings can be achieved and demonstrate actuals
Reduced first cost of new systems / design
Validation of performance of new HVAC technologies through utility field test
Stake holders requesting post occupancy building performance data and analysis and reporting
Electric utility need for resources to meet growing loads, and/or to replace oil and coal fired power plants
Need to optimize use of ambient or indoor conditions, e.g., economizer, indoor ventilation controls, and heat recovery
Current energy modeling engines under development by DOE (energy +) do not have wide market adoption because perceived to be too detailed, too difficult to use - and hence to expensive to use. Tools for accelerating inputs, and accelerating computation time (2 minutes or less) are needed
Need to account for large number of variables in building modeling, standards, and training
Need benchmarking categories at end use level; to improve modeling and better represent real world conditions
Need to quantify and deliver predictable energy savings from HVAC distribution zone control systems
Need functional performance test definition for factory testing
Need to tie model to building needs / loads
Energy efficiency metering to pay for performance
Building simulation software
Validated building energy models
Field validation of variable speed system performance (variable capacity)
NREL; MNCEE; PNNL; utilities testing RTU retrofit devices
Do field tests to compare building models to actual energy use to provide feedback to help develop more accurate building simulations
NIST; EEB HUB
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Do field tests to compare building models to actual energy use; provide feedback to help develop more accurate building simulations. Do field tests to compare building model to actual energy use when built. Provide feedback to building modeling developers to help them develop more accurate building simulations.

Existing research: Building modeling developers to help them develop more accurate building simulations. Teams at the National Institute of Standards and Technology (NIST) and the U.S. Department of Energy (DOE) are working in this area at its Energy Efficient Buildings Hub (EEB HUB).

- NIST's Energy and Environment Division is engaged in one facet of this research with their "Design and In-Situ Performance of Vapor Compression System" project. More information in Appendix B.
- EEB HUB: Located in Philadelphia, Pennsylvania. They plan to devote a significant part of their efforts to comparing measured performance to modeled performance, including computational tools that will enable robust and rapid design of integrated building systems (http://www.eebhub.org/).
- *[Summaries of other existing research pending]*

Key research questions:

1. Questions not yet specified.

Field validation of variable speed system performance (variable capacity). (Summary not yet provided.)

Existing research: National Renewable Energy Laboratory (NREL), Minnesota Center for Energy and Environment (MNCEE), and Pacific Northwest National Laboratory (PNNL)plus half-dozen utilities testing RTU retrofit devices.

- *[Summaries of existing research pending]*

Key research questions:

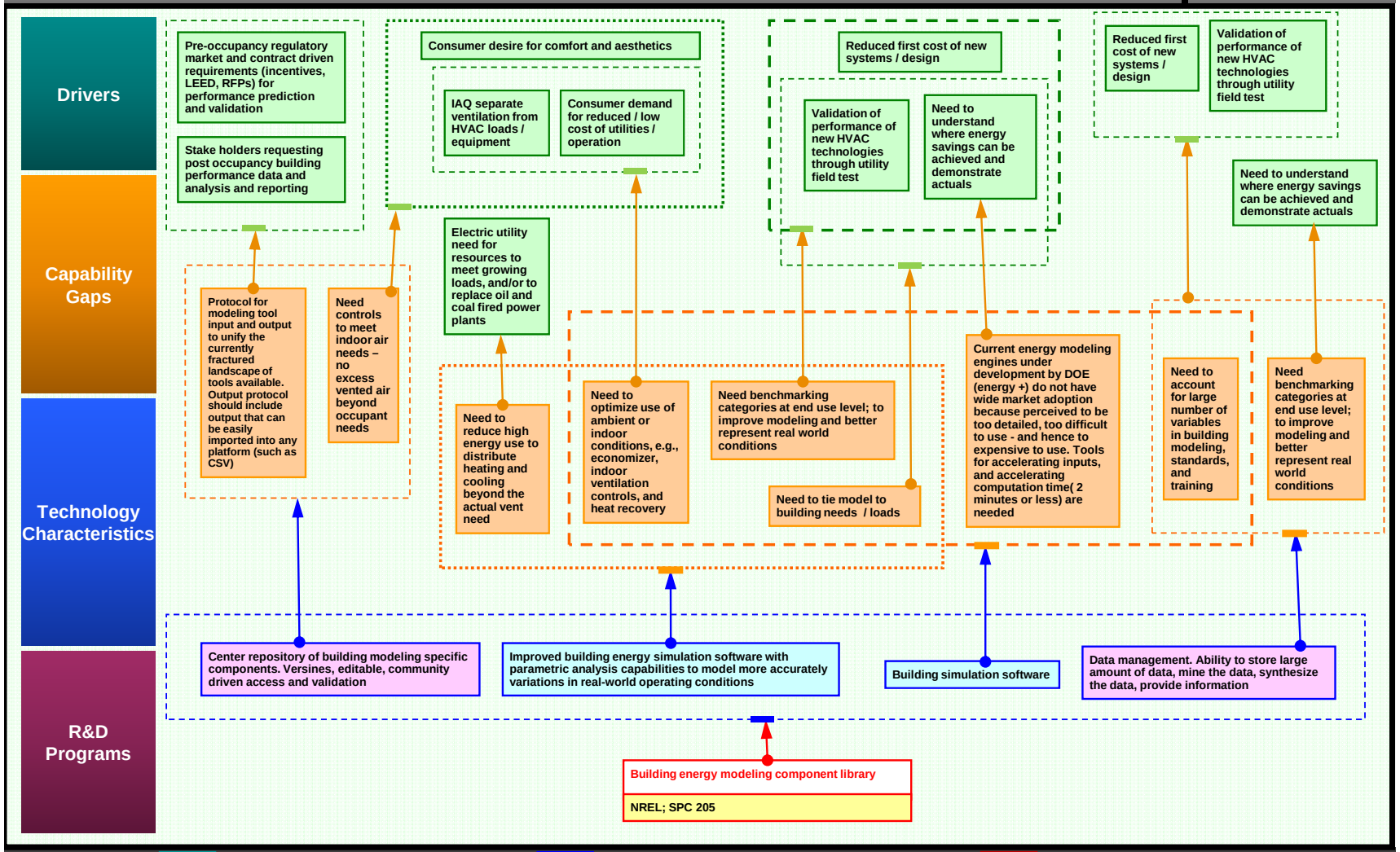
1. Questions not yet specified.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Modeling, Lab and Field Testing (8 of 10)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Building energy modeling component library. (Summary not yet provided.)

Existing research: National Renewable Energy Laboratory (NREL) building component library, SPC 205.

- *[Summaries of existing research pending]*

Key research questions:

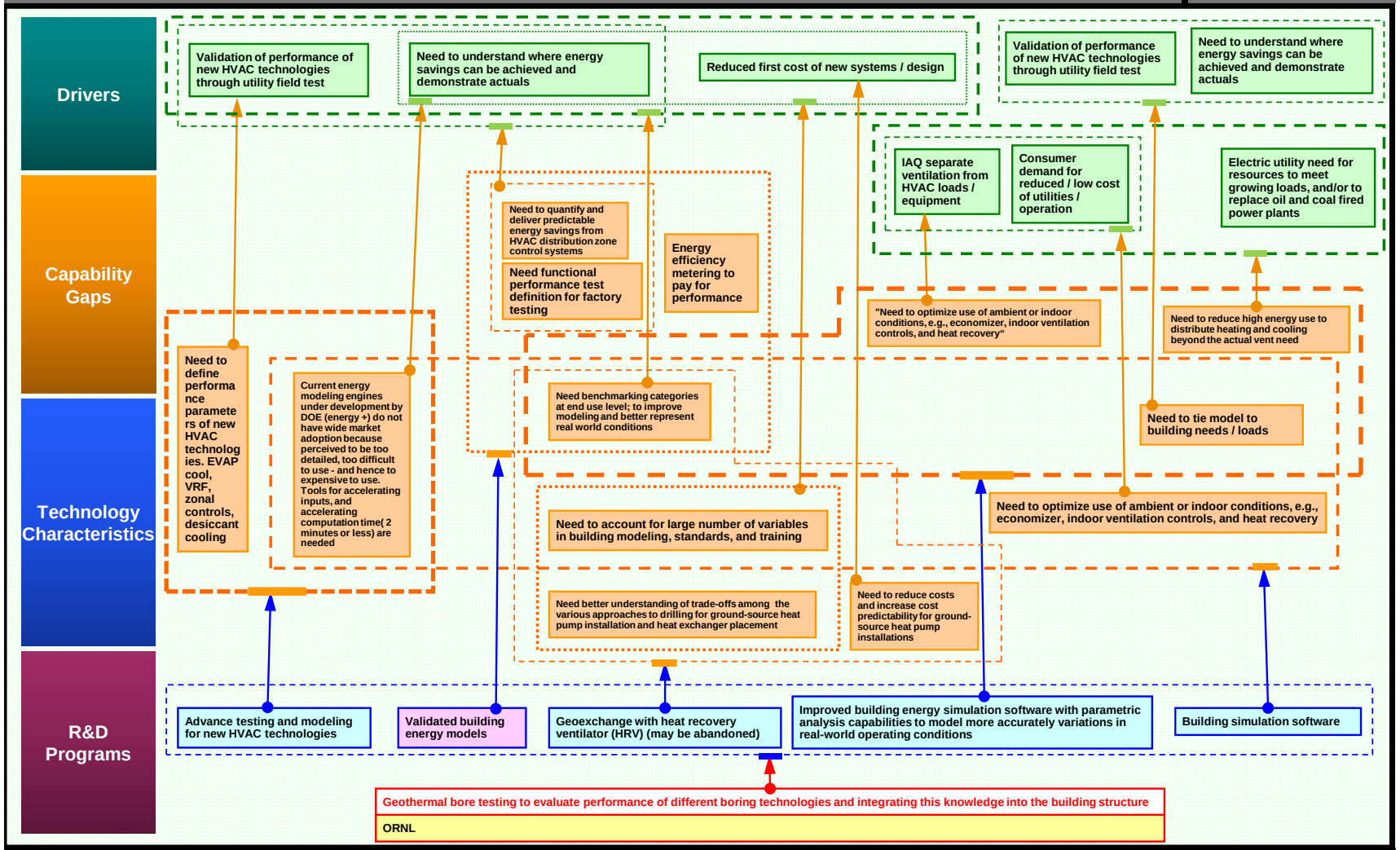
1. Questions not yet specified.

Product/Service Area : **HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Modeling, Lab and Field Testing (9 of 10)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

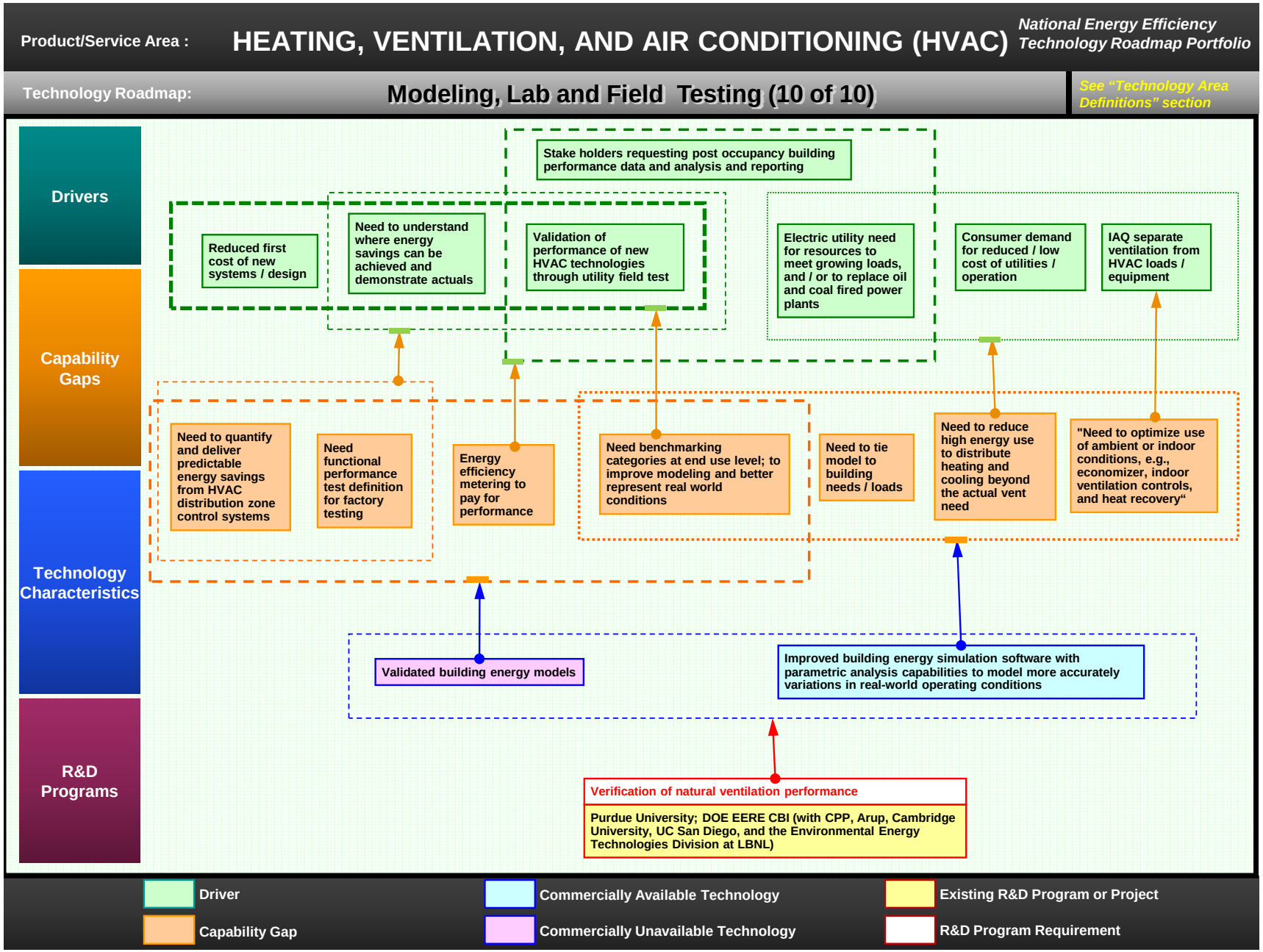
Geothermal bore testing for different boring technology performance, integrating into the building structure. (It would be worthwhile to have some good data on what kind of drilling is generally most cost-effective under certain conditions for geothermal heating and cooling systems. Test the different methods against each other for cost-effectiveness. If not already available, develop a best practices guide for what conditions favor which drilling techniques.

Existing research: Oak Ridge National Laboratory (ORNL).

- In January 2011, E Source offered the following citations on work that may be relevant:
  - Harvey M. Sachs, *Geology and Drilling Methods for Ground-Source Heat Pump Installations: An Introduction for Engineers* (Atlanta, Ga.: American Society of Heating, Refrigerating, and Air-Conditioning Engineers, 2002).
  - Kevin B. McCray, "Guidelines for the Construction of Vertical Boreholes for Closed Loop Heat Pump Systems," (Westerville, Ohio: National Ground Water Association, n.d.) (http://intraweb.stockton.edu/eyos/energy_studies/content/docs/proceedings/MCCRA.PDF).
  - Publications through the National Groundwater Association (www.ngwa.org).
- ORNL: See Appendix B.

Key research questions:

1. Questions not yet specified.


Product/Service Area :
HEATING, VENTILATION, AND AIR CONDITIONING (HVAC)
National Energy Efficiency Technology Roadmap Portfolio
Technology Roadmap:
Modeling, Lab and Field Testing (10 of 10)
See "Technology Area Definitions" section
Drivers
Capability Gaps
Technology Characteristics
R&D Programs
Stake holders requesting post occupancy building performance data and analysis and reporting
Reduced first cost of new systems / design
Need to understand where energy savings can be achieved and demonstrate actuals
Validation of performance of new HVAC technologies through utility field test
Electric utility need for resources to meet growing loads, and / or to replace oil and coal fired power plants
Consumer demand for reduced / low cost of utilities / operation
IAQ separate ventilation from HVAC loads / equipment
Need to quantify and deliver predictable energy savings from HVAC distribution zone control systems
Need functional performance test definition for factory testing
Energy efficiency metering to pay for performance
Need benchmarking categories at end use level; to improve modeling and better represent real world conditions
Need to tie model to building needs / loads
Need to reduce high energy use to distribute heating and cooling beyond the actual vent need
"Need to optimize use of ambient or indoor conditions, e.g., economizer, indoor ventilation controls, and heat recovery"
Validated building energy models
Improved building energy simulation software with parametric analysis capabilities to model more accurately variations in real-world operating conditions
Verification of natural ventilation performance
Purdue University; DOE EERE CBI (with CPP, Arup, Cambridge University, UC San Diego, and the Environmental Energy Technologies Division at LBNL)
Driver
Capability Gap
Commercially Available Technology
Commercially Unavailable Technology
Existing R&D Program or Project
R&D Program Requirement

R&D Program Summaries

Verification of natural ventilation performance. (Summary not yet provided.)

Existing research: Purdue University did a lit review. The U.S. Department of Energy (DOE) Office of Energy Efficiency and Renewable Energy (EERE) Commercial Building Initiative (CBI) has a series of projects on this (collaborators include CPP, Arup, Cambridge University, UC San Diego, and the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory (LBNL)).

- *[Summaries of existing research pending]*

Key research questions:

1. Questions not yet specified.

Sensors, Meters, Energy Management Systems Roadmaps

This section contains the following roadmaps:

- Smart Device-Level Controls Responsive to User and Environment
- Easy / Simple User Interface Controls
- Energy Management Services
- Low-Cost Savings Verification Techniques
- Real-Time Smart Electric Power Measurement of Facilities
- Enterprise Energy and Maintenance Management Systems

Other relevant sources:

The list below is intended to be broadly representative rather than exhaustive and will be updated as new information becomes available.

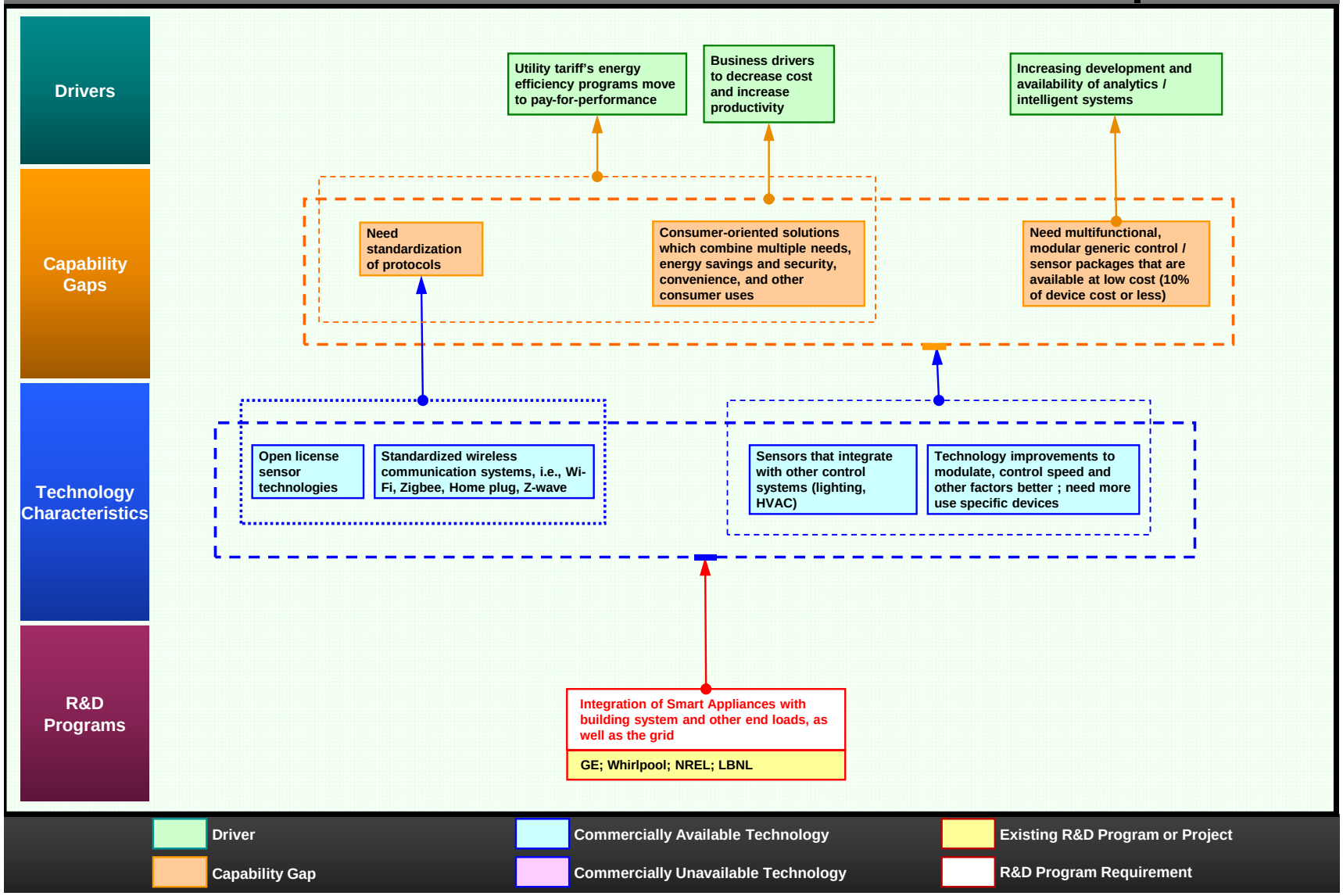
Sources pending.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Smart Device-Level Controls Responsive to User and Environment (1 of 5)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Integration of smart appliances with building system and other end use loads, as well as the grid. To maximize benefits of small appliances for grid and energy savings(driver value to both utility and building users).

Existing research: General Electric (GE), Whirpool, National Renewable Energy Laboratory (NREL), Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

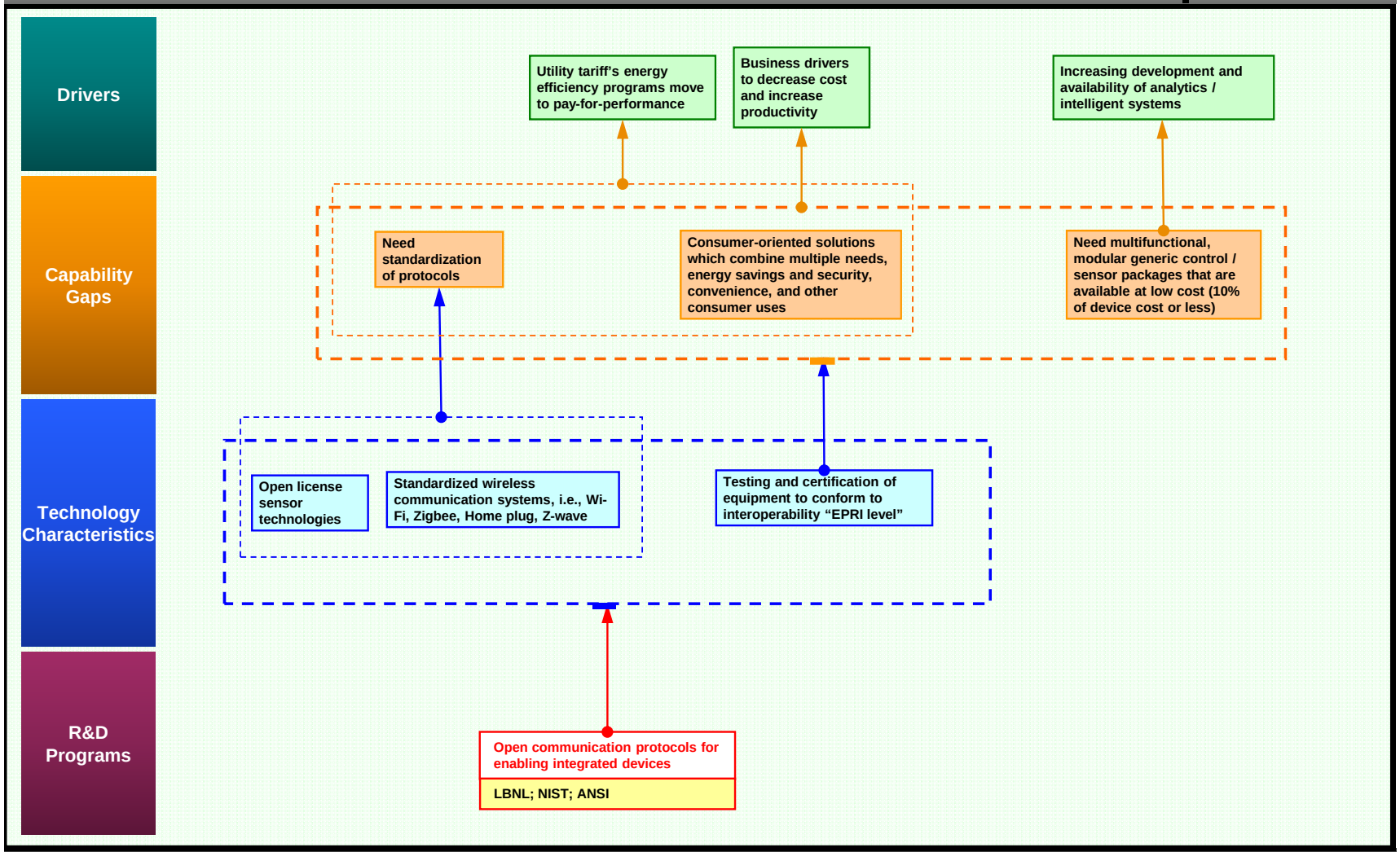
1. What are the practical limits for load shifting in an effective way without interfering with comfort on service (power, duration, frequency)?
2. What are the potential energy savings at the end use level (not just load shifting) as a result of smart communicating appliances?
3. Can we leverage safety, security, and convenience benefits to get consumers to interest in smart appliances?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Smart Device-Level Controls Responsive to User and Environment (2 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Open communication protocols for enabling integrated devices. Lots of building systems cannot communicate to each other. This obstacle to communication limits interoperability and effective integrated building controls.

Existing research: Lawrence Berkeley National Laboratory (LBNL), National Institute of Standards and Technology (NIST)(ZigBee and WiFi); American National Standards Institute (ANSI).

- *[Summaries of existing research pending]*

Key research questions:

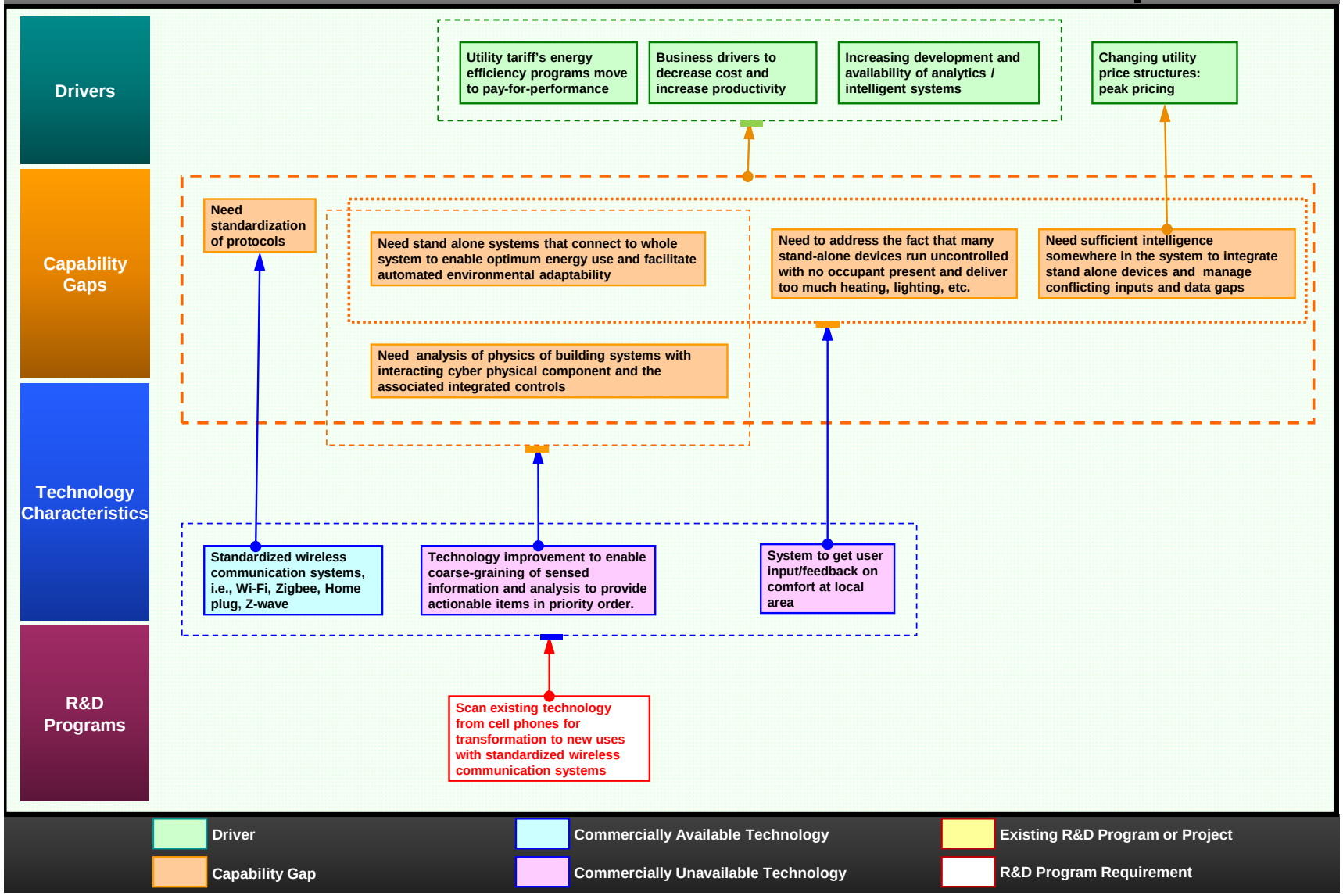
1. What kind of universal performance specification could be developed to motivate OEMs to interoperate open communication protocols into their products?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Smart Device-Level Controls Responsive to User and Environment (3 of 5)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Scan existing technology from cell phones for transformation to new uses with standardized wireless communication systems. Cell phones are now ubiquitous and versatile. Cell phones and buildings can exchange information. Cell phones are mobile sensors and remote interface / communication devices. Operators can require alarms or change control settings remotely, and occupants can send preferences to the central system.

One example of such a system is the iPhone app for General Motors' Chevrolet Volt electric vehicle that allows users to monitor charging status and can be notified when charging ends (either on-schedule or prematurely). This system seems like it could easily lend itself to vehicle controllability via GM's On Star system. See http://gm-volt.com/2009/12/10/chevy-volt-will-connect-to-blackberry-iphone-and-apps/, http://www.chevrolet.com/volt-electric-car/. E Source reported in February 2011 that this application of cell phone technology appeared to be the only such project currently in development.

Existing research: None identified.

Key research questions:

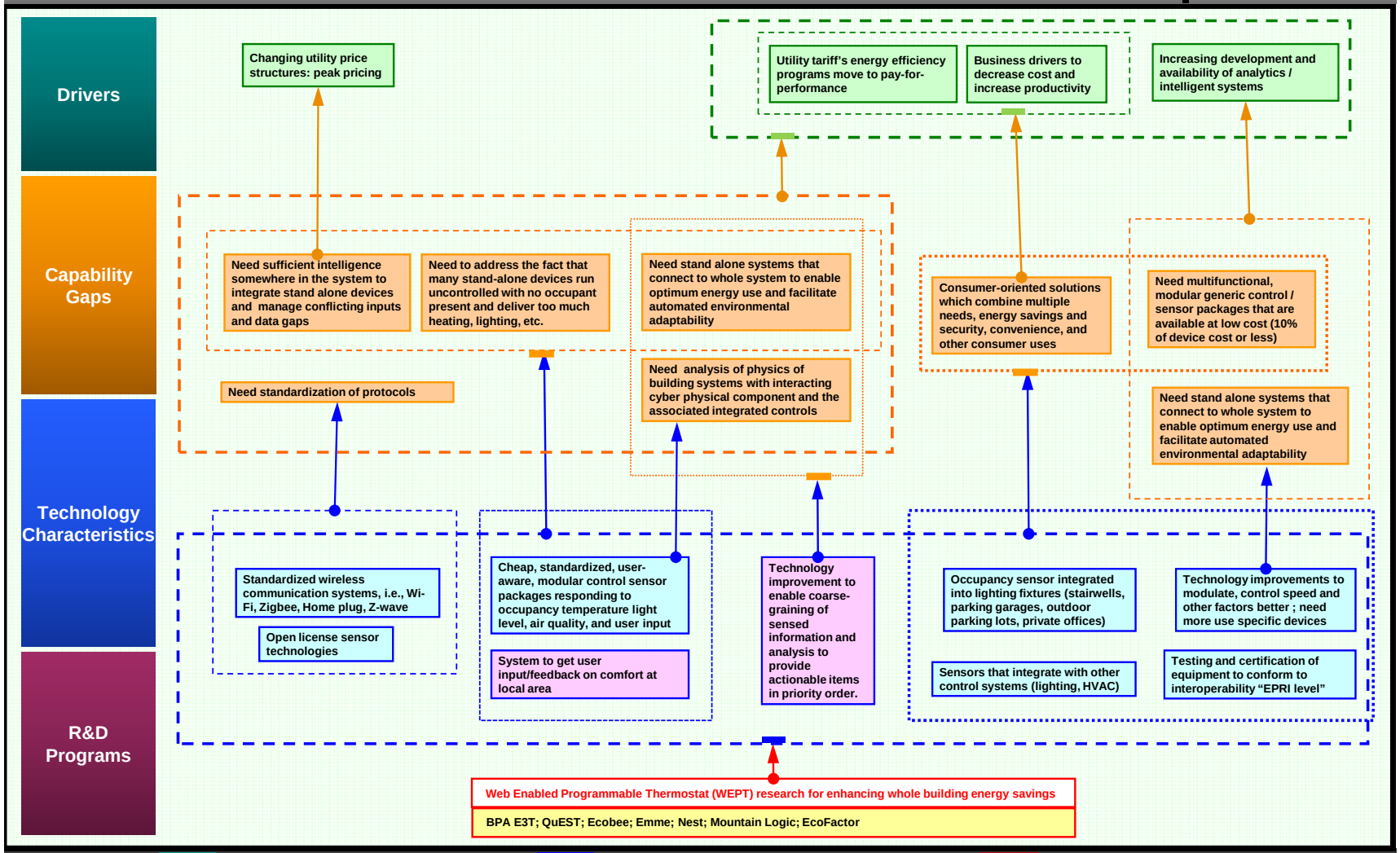
1. What is an effective system architecture for using cell phones in commercial applications?
2. What are the opportunities for integrating cell phones into energy management and building control systems?
3. How can location information be used by energy management and building control systems?
4. What sensors could be added/built in to cell phones to make them more useful as part of building energy management systems?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Smart Device-Level Controls Responsive to User and Environment (4 of 5)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Web enabled programmable thermostat research for enhancing whole building energy savings. Web enabled programmable thermostats that control HVAC equipment and integrate with other systems can help deliver significant reductions in energy use and improve occupant comfort and convenience.

Existing research: Bonneville Power Administration (BPA) Energy Efficiency Emerging Technologies (E3T), QuEST, Ecobee, Nest, Mountain Logic, EcoFactor.

- Bonneville Power Administration's Energy Efficiency Emerging Technology (E3T) team is working with Quantum Energy Services (QuEST) and the Clark Public Utilities District to evaluate WEPT systems in modular classroom buildings at Several Washington State School Districts and develop a whole-building regression analysis tool to estimate and verify HVAC savings; see http://www.bpa.gov/energy/n/emerging_technology/WEPT.cfm.
- *[Summaries of other existing research pending]*

Key research questions:

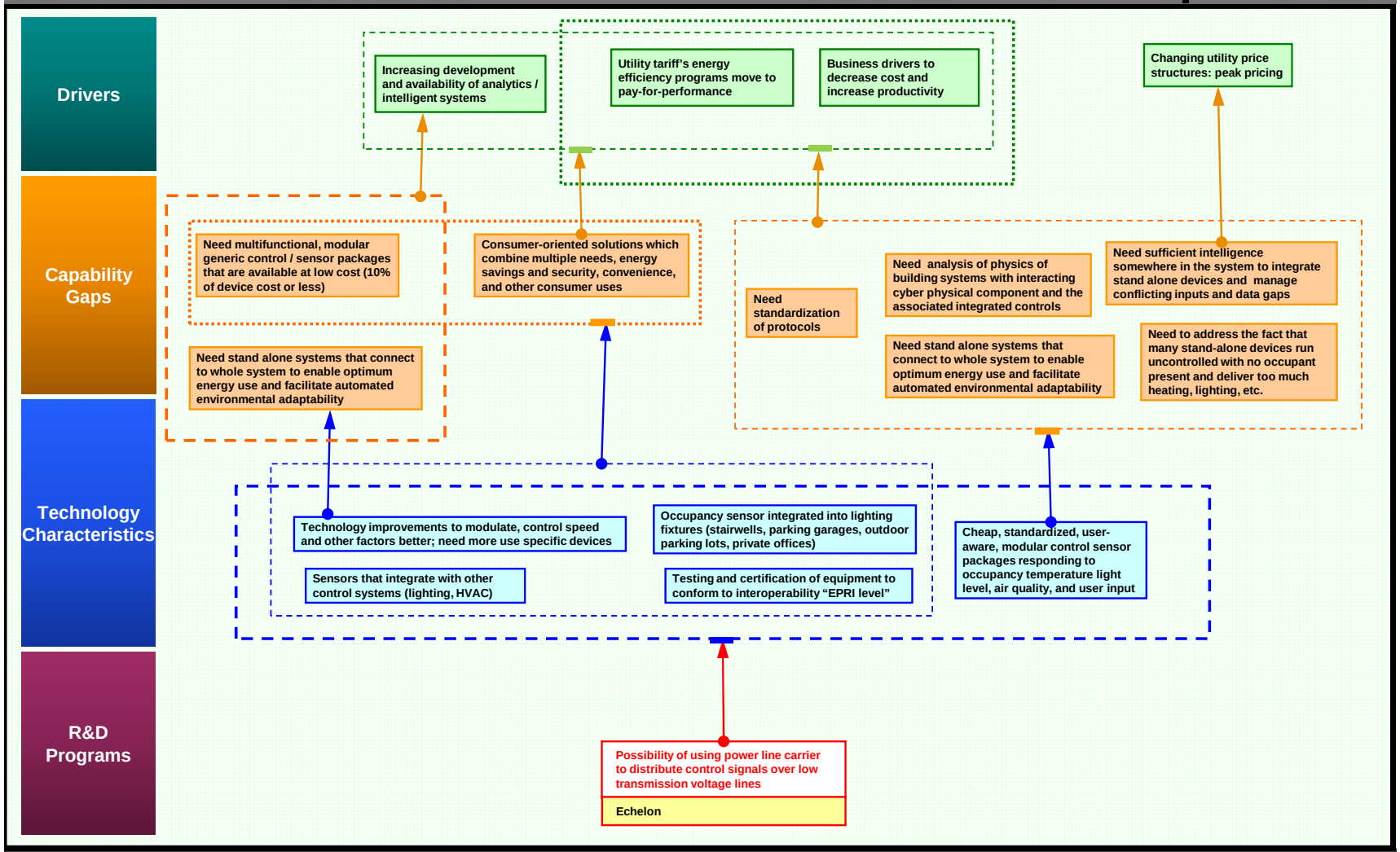
1. What is the minimum dataset needed to be collected?
2. How much energy is existing web based systems saving?
3. How can / is data being used / processed to save energy?
4. What additional opportunities to save more energy with all systems?
5. What level of control / automation is needed?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Smart Device-Level Controls Responsive to User and Environment (5 of 5)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Possibility of using power line carrier to distribute control signals over low transmission voltage lines. The attraction of power line carrier signals for controls is compelling. Power lines are available virtually wherever control is needed. This eliminates the need for installing an additional set of wires or more expensive wireless equipment. If barriers to implementing this in commercial applications could be removed, it could simplify and reduce the cost of installation of controls, especially for retrofit.

Existing research: Echelon.

- *[Summaries of existing research pending]*

Key research questions:

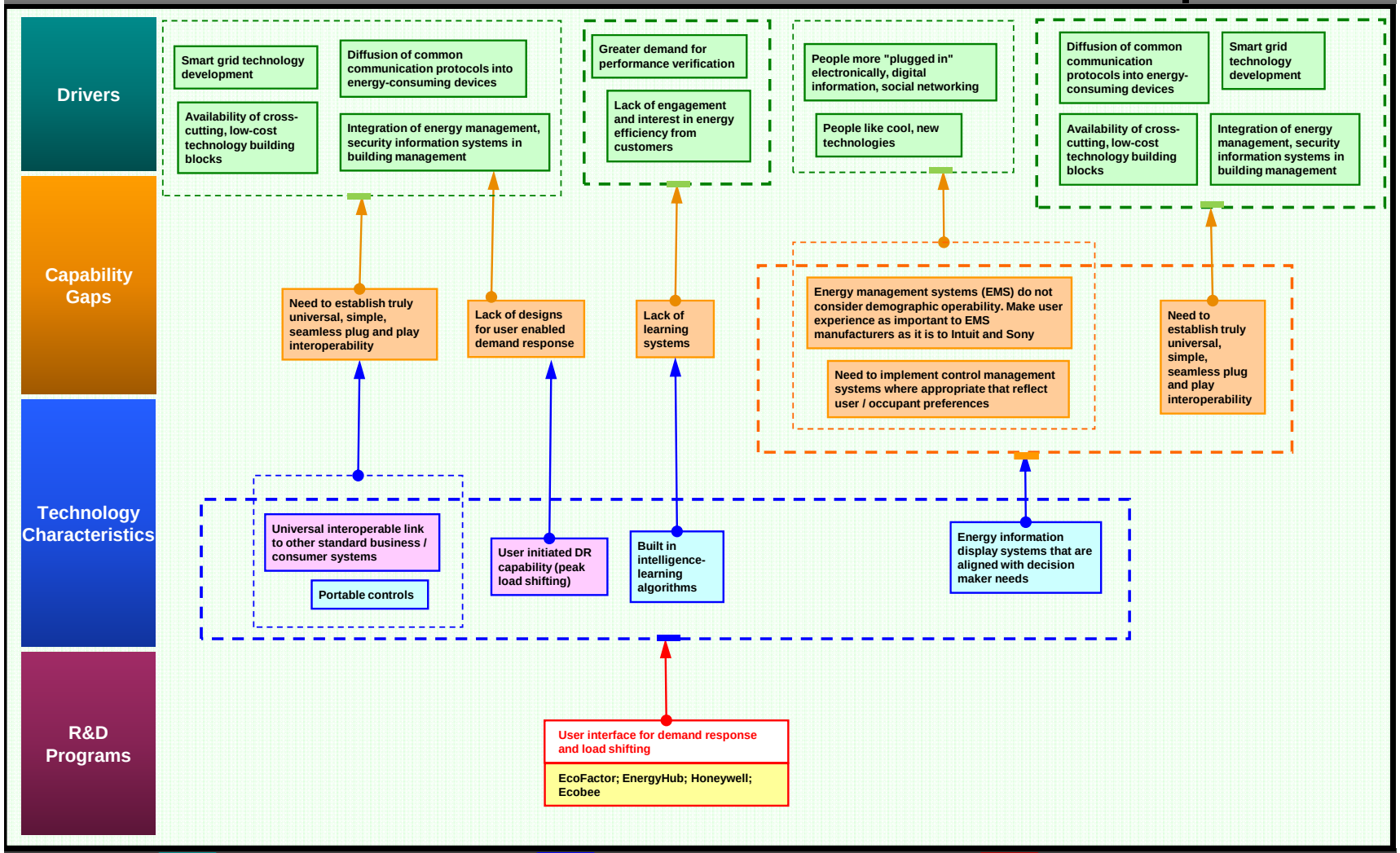
1. Is it cheaper or cost effective?
2. What are the full characterizations of data transfer capabilities (e.g. bandwidth, security) compared to wireless protocols?
3. What are current roadblocks for large scale implementation?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Easy / Simple User Interface Controls (1 of 5)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

User interface for demand response and load shifting. Demand response (DR) has a large consumers acceptance barrier due to perceived inconvenience. User interfaces can learn occupant preferences and provide "seamless demand response" and add value to EMS.

Existing research: EcoFactor, EnergyHub, Honeywell, and Ecobee.

- *[Summaries of existing research pending]*

Key research questions:

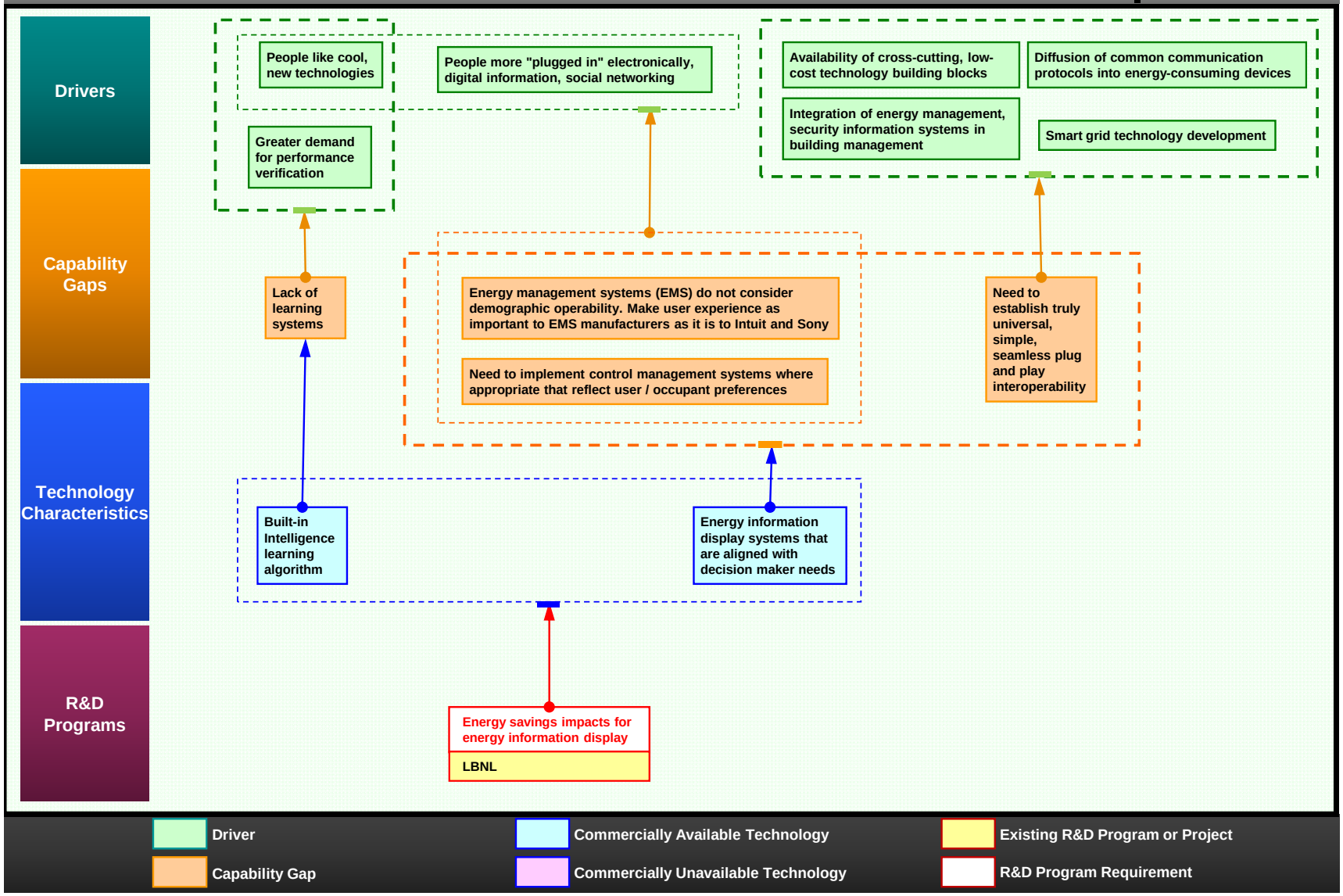
1. How can we program devices for DR?
2. How can customer feedback mitigate perceived inconvenience of demand response?
3. How can two-way communication enable better DR program?
4. How can DR feature be used for site renewables integration?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Easy / Simple User Interface Controls (2 of 5)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Energy savings impacts for energy information display. R&D and pilot tests are ongoing in this area to determine the persistence of energy efficiency savings of in-home energy displays (IHDs).

Existing research: Lawrence Berkeley National Laboratory (LBNL).

- Researchers at the Brattle Group reviewed twelve utility pilot programs in the U.S.A., Canada, and Japan focused on the energy conservation impact of IHDs and customer receptivity to these technologies. They conclude that consumers are more likely to use energy up to 7% more efficiently with the direct feedback provided by IHDs, and up to 14% more efficiently when IHDs are coupled with an electricity prepayment system. This study of pilot programs also finds that IHD feedback has positive time-of-use rates impacts upon demand response programs. See Ahmad Faruqui, Sanem Sergici, and Ahmed Sharif, "The Impact of Informational Feedback on Energy Consumption: A Survey of the Experimental Evidence," Energy 35 (2010), 1598-1608.
- Alan Meier, Senior scientist in the Energy Analysis Department of the Lawrence Berkeley National Laboratory (LBNL), studies ways to reduce energy consumption by analyzing how both people and equipment use energy. His research involves buildings, equipment and, transportation, including residential thermostats and real-time energy displays. See http://eetd.lbl.gov/ea/akmeier//.

Key research questions:

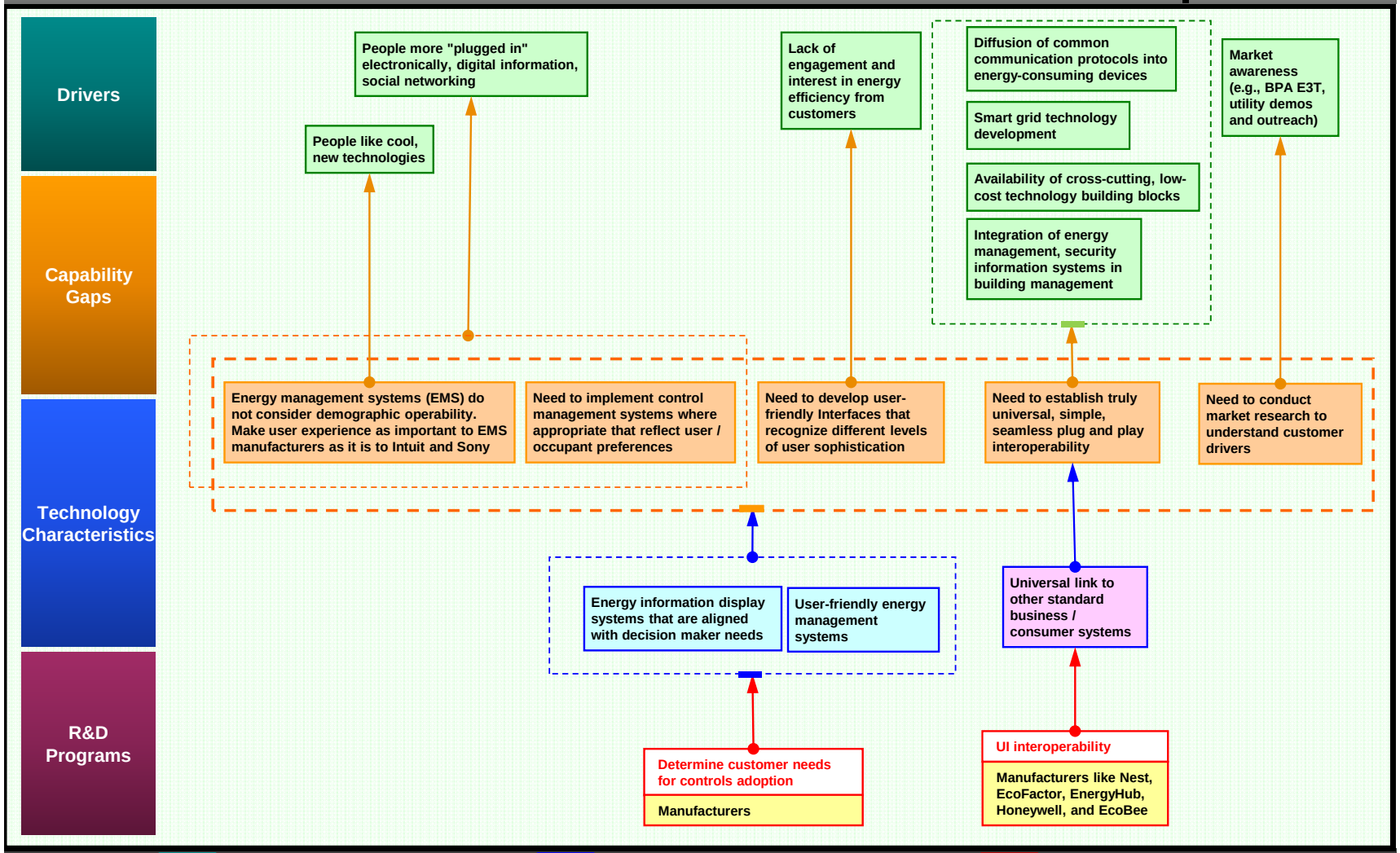
1. Questions not yet specified.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Easy / Simple User Interface Controls (3 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

UI interoperability. User interface (UI) enhancement through application programming interfaces (APIs) for energy management systems (EMS) and other applications.

Existing research: Manufacturers.

- *[Summaries of existing research pending]*

Key research questions:

1. What are the appropriate "APIs" that would link EE to top SW system, not just BMs but ERP, outlook, etc.

Determine customer needs for controls adoption. Conduct R&D to determine customer needs for easy/simple GUI for controls and then design R&D profile to develop a comprehensive/integrated user interface system that customer can understand and use and test it in customer sites.

Existing research: Manufacturers like Nest; EcoFactor; EnergyHub; Honeywell and EcoBee.

- *[Summaries of existing research pending]*

Key research questions:

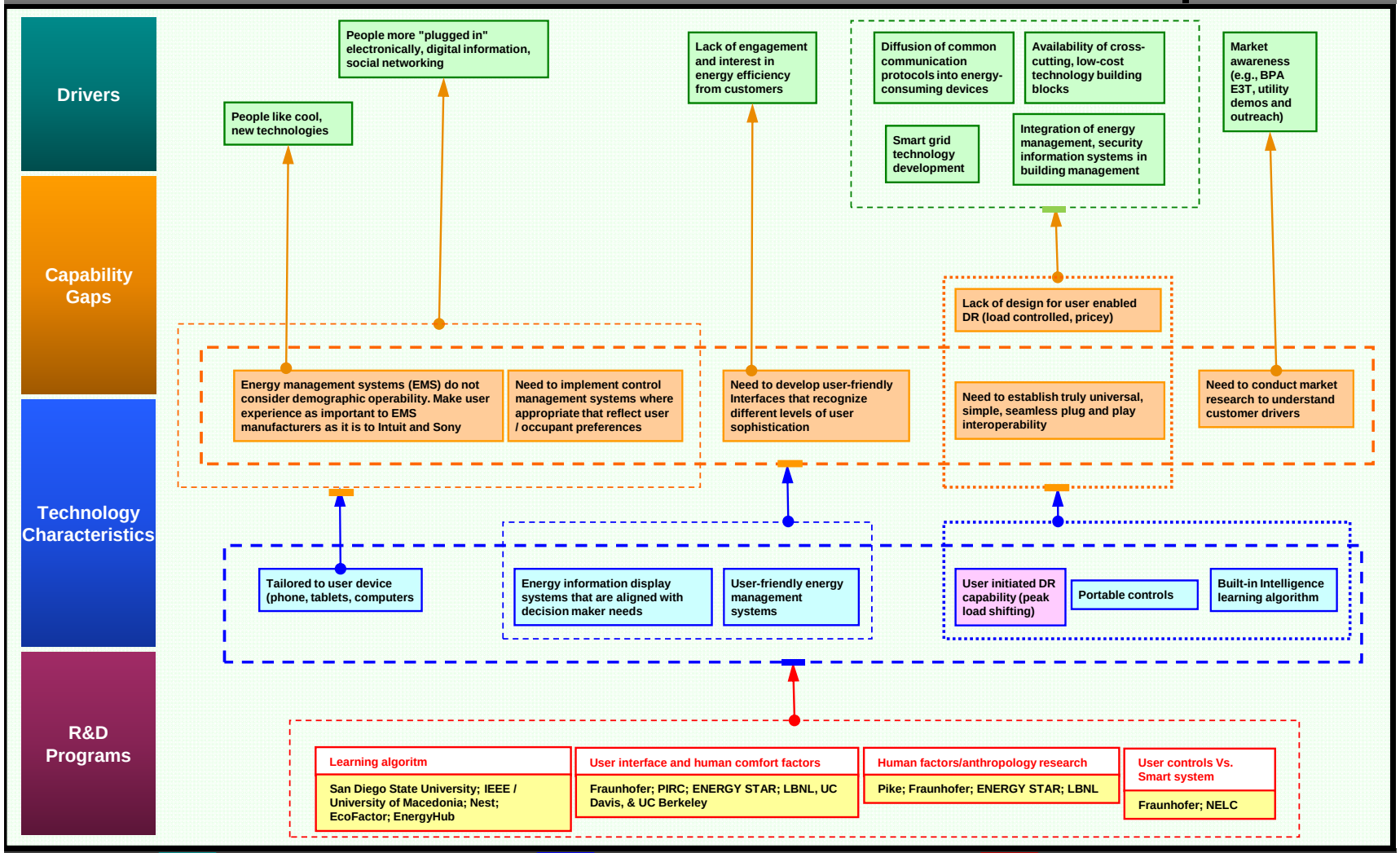
1. Which type of GUI's the customer will mostly likely prefer?
2. How does the integrated system, feedback and protocols act as sub system in a manner to enable simple customer experience?
3. what will be the behavior change and how to quantify and evaluate the change?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Easy / Simple User Interface Controls (4 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

User controls vs. smart system. As system become smarter and learn to improve efficiency, what level of user override should be allowed?

Existing research: Fraunhofer; National Energy Leadership Corps (NELC).

- *[Summaries of existing research pending]*

Key research questions:

1. In what circumstances should user override be allowed? How should this parameters be incorporated into user interface?

Learning algorithm. User inputs and outputs with smart/learning EMs systems.

Existing research: San Diego State University, Institute of Electrical and Electronics Engineers (IEEE) with the University of Macedonia, Nest, EcoFactor, EnergyHub.

- *[Summaries of existing research pending]*

Key research questions:

1. What are the variables and parameters that a learning systems need to utilize?
2. How much guidance along those lines can/should the user provide either when setting up or during usage of the system?
3. How much output of "smart" system should be shared with user and to what end?

User interface and human comfort factors. What user interfaces link to more advanced human comfort system, e.g., radiant, conductive and ventilation system that affect comfort envelope.

Existing research: Fraunhofer, U.S. Department of Energy Building America Program Partnership for Improved Residential Construction (PIRC), ENERGY STAR, National Renewable Energy Laboratory (NREL). Also a collaboration among Lawrence Berkeley National Laboratory (LBNL), University of California Davis, and University of California Berkeley.

- Subject matter experts reported in September 2012: "LBNL/UC Davis/UC Berkeley (on thermostats)."
- NREL: See Appendix B.
- *[Summaries of existing research pending]*

Key research questions:

1. Beyond air temp, what user interfaces best represent/link to user perception of comfort to control advanced HVAC systems?
2. similarly for lighting, what new SSL systems, tasks and ambient, what user interface best interact with user perceptions/needs?

Human factors and anthropometric research. Research into human factors/resources to energy management systems to explore what are the key characteristics.

Existing research: Pike, Fraunhofer, ENERGY STAR (for thermostats initially); LBNL.

- *[Summaries of existing research pending]*

Key research questions:

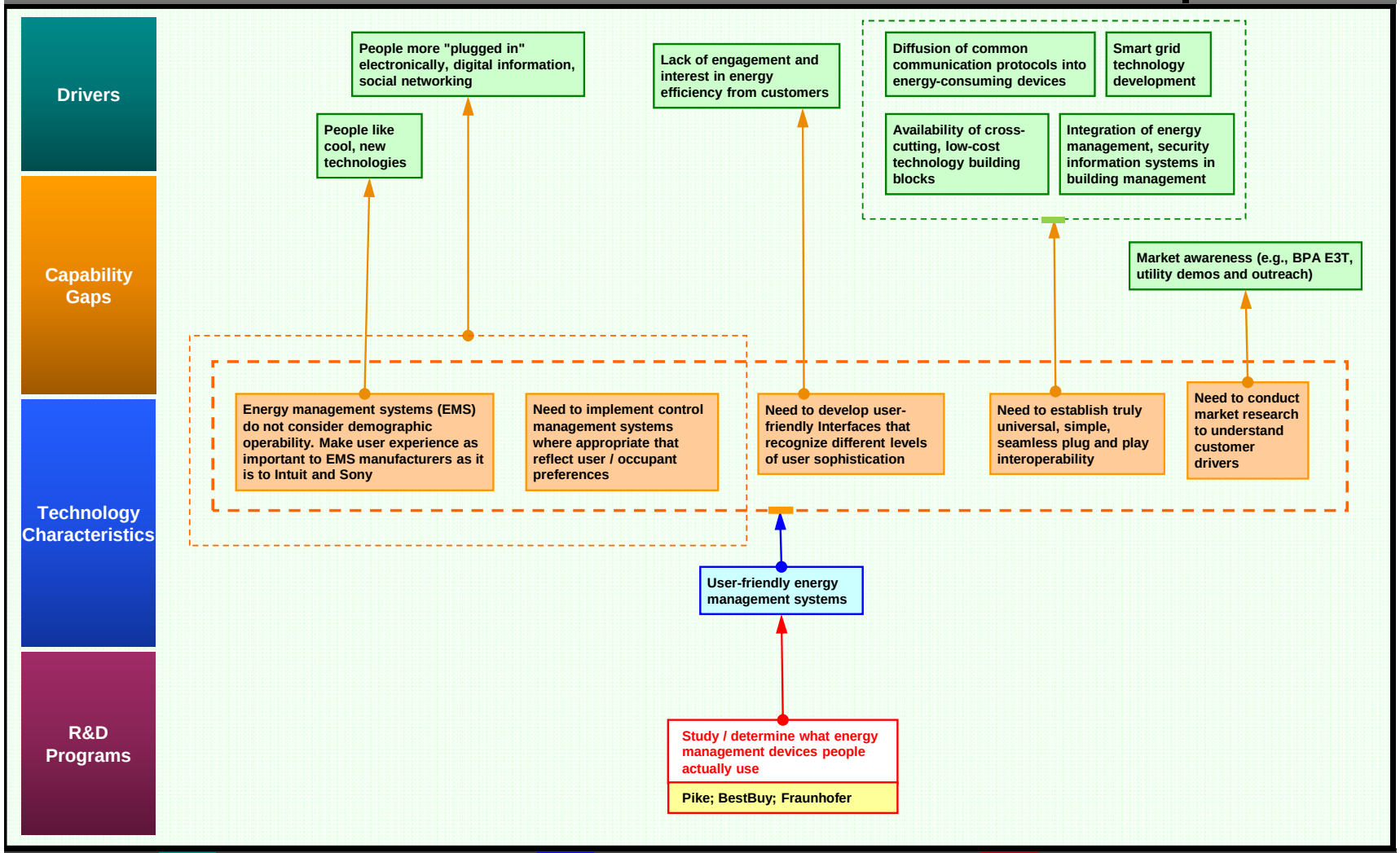
1. What are different needs for different sector decision makers—e.g building manager compared to residential customer compared to industrial plant manager?
2. What other apps should energy management be integrated with customers?
3. What devices should use interface be integrated into?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Easy / Simple User Interface Controls (5 of 5)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Study / determine what energy management devices people actually use. E Source reported in February 2011 that, to date, there has been much more research about which energy management devices (EMDs) people do not use, and little positive research relating to which EMDs people actually do use. This research suggests that consumers' good intentions in buying programmable thermostats, ECM furnaces, and other products do not often lead to overall energy savings because many consumers do not use take full advantage of the products' features or use the features.

Existing research: Pike, BestBuy and Fraunhofer.

- *[Summaries of existing research pending]*

Key research questions:

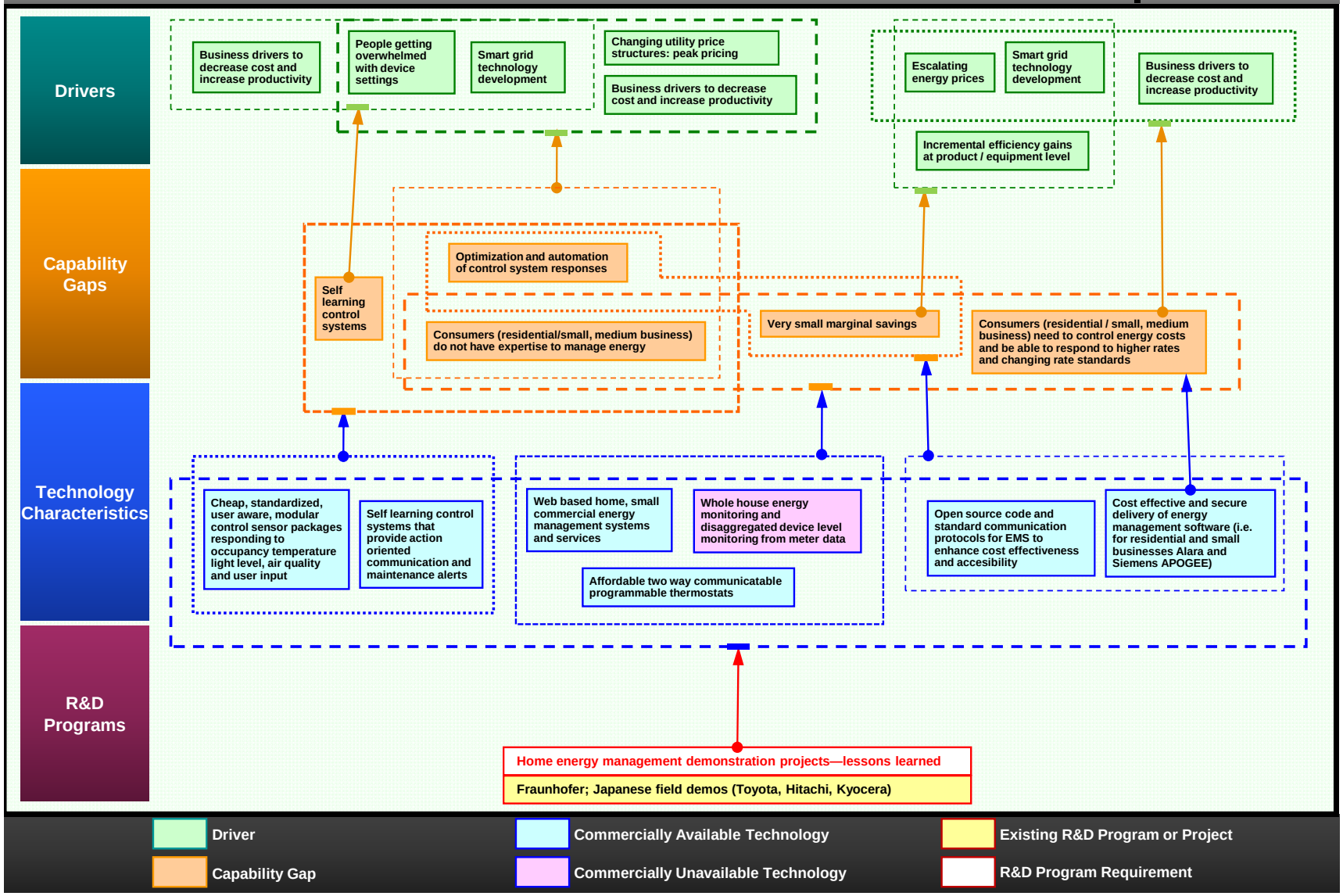
1. Why don't consumer use the feature?
2. What is buyer's motivation to purchase?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Energy Management Services (1 of 4)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Home energy management demonstration projects—lessons learned. One of the foci of the federal stimulus package (American Recovery and Reinvestment Act (ARRA) of 2009, Public Law 111-5) was to foster energy efficiency by promoting and/or funding good home energy management http://www.recovery.gov/Pages/default.aspx).

Existing research: Fraunhofer demo lab; Japanese field demos (Toyota, Hitachi, Kyocera.

Key research questions:

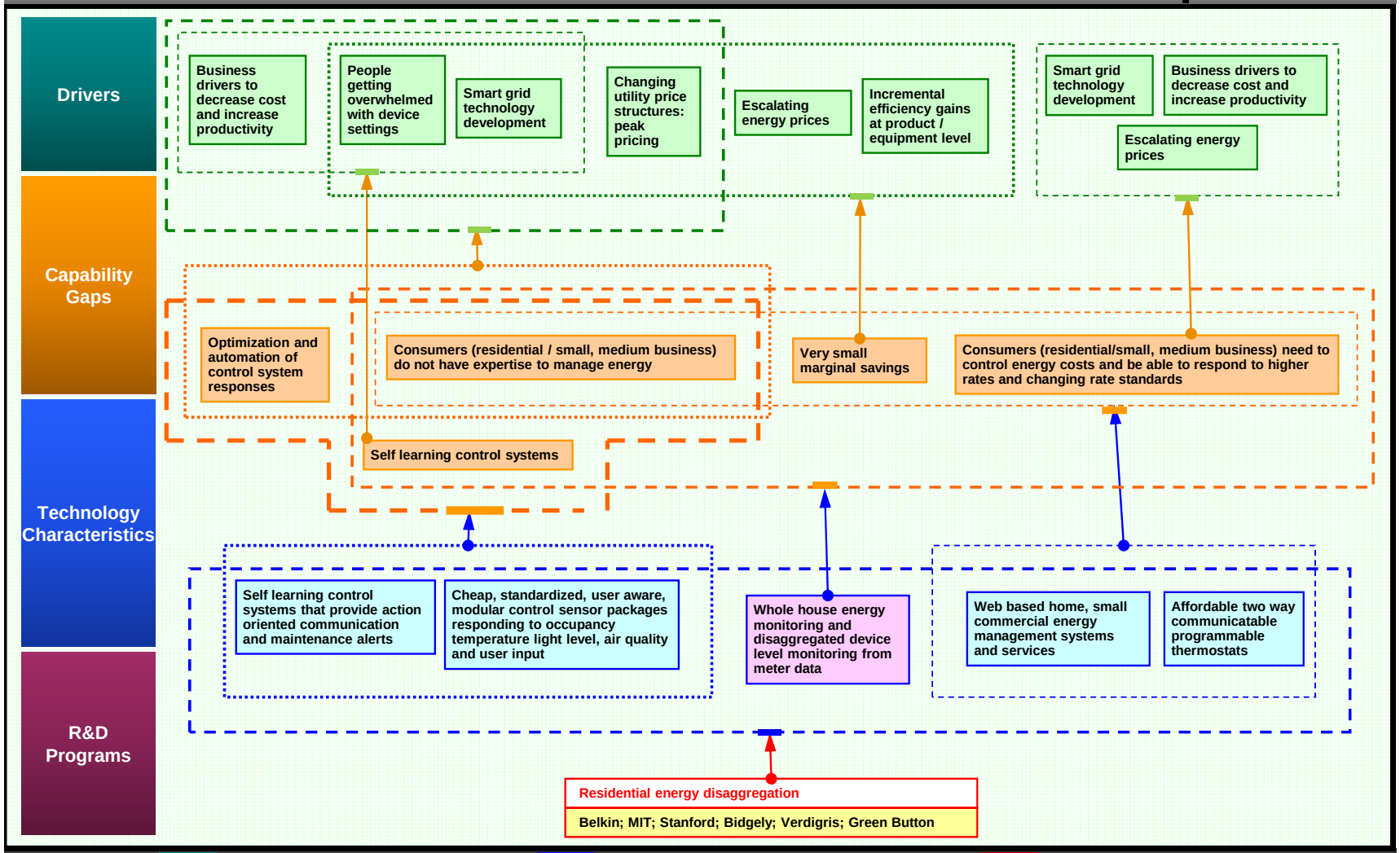
1. Finding and synchronizing learnings across funded projects?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Energy Management Services (2 of 4)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Residential energy disaggregation. Disaggregate whole house energy consumption by device level. Use smart meters or CTC lamps to read load. Use software to disaggregate load and inform homeowners of energy use with suggestions to save energy.

Existing research: Belkin, Massachusetts Institute of Technology (MIT), Stanford University, Bidgely, Verdigris, Green Button.

- *[Summaries of existing research pending]*

Key research questions:

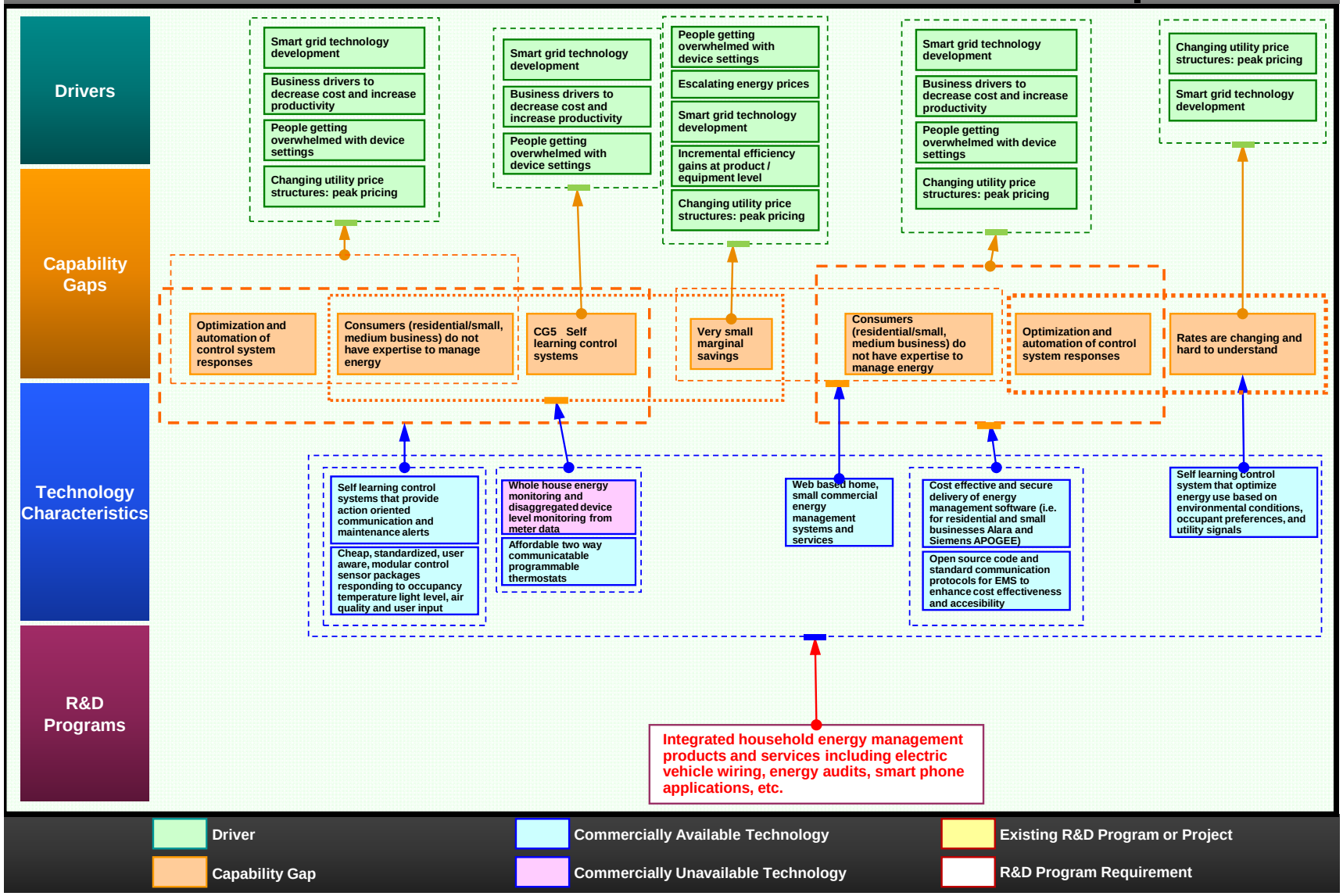
1. How much energy do homeowners save by knowing their energy use?
2. Which level of granularity is necessary to achieve significant savings? (1 kHz, 1Hz, 1min, 1hr)?
3. What suggestions will the software provide?
4. How can the utility provide a rebate for these tools?
5. What is the cost per home?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Energy Management Services (3 of 4)**

See "Technology Area Definitions" section



Integrated household energy management products and services including electric vehicle wiring, energy audits, smart phone applications, etc. In November 2011, Minnesota-based Best Buy, Inc., introduced an enhanced Home Energy Management Department that provides tools and education through easily-accessible on-site and online sources (http://www.bestbuy.com/site/regularCat%3Apcmcat257000050007/Home-Energy-Why-Best-Buy/pcmcat257000050007.c?id=pcmcat257000050007). This approach could serve as a useful model for how to engage the under-served residential energy management market.

Existing research: None identified.

Key research questions:

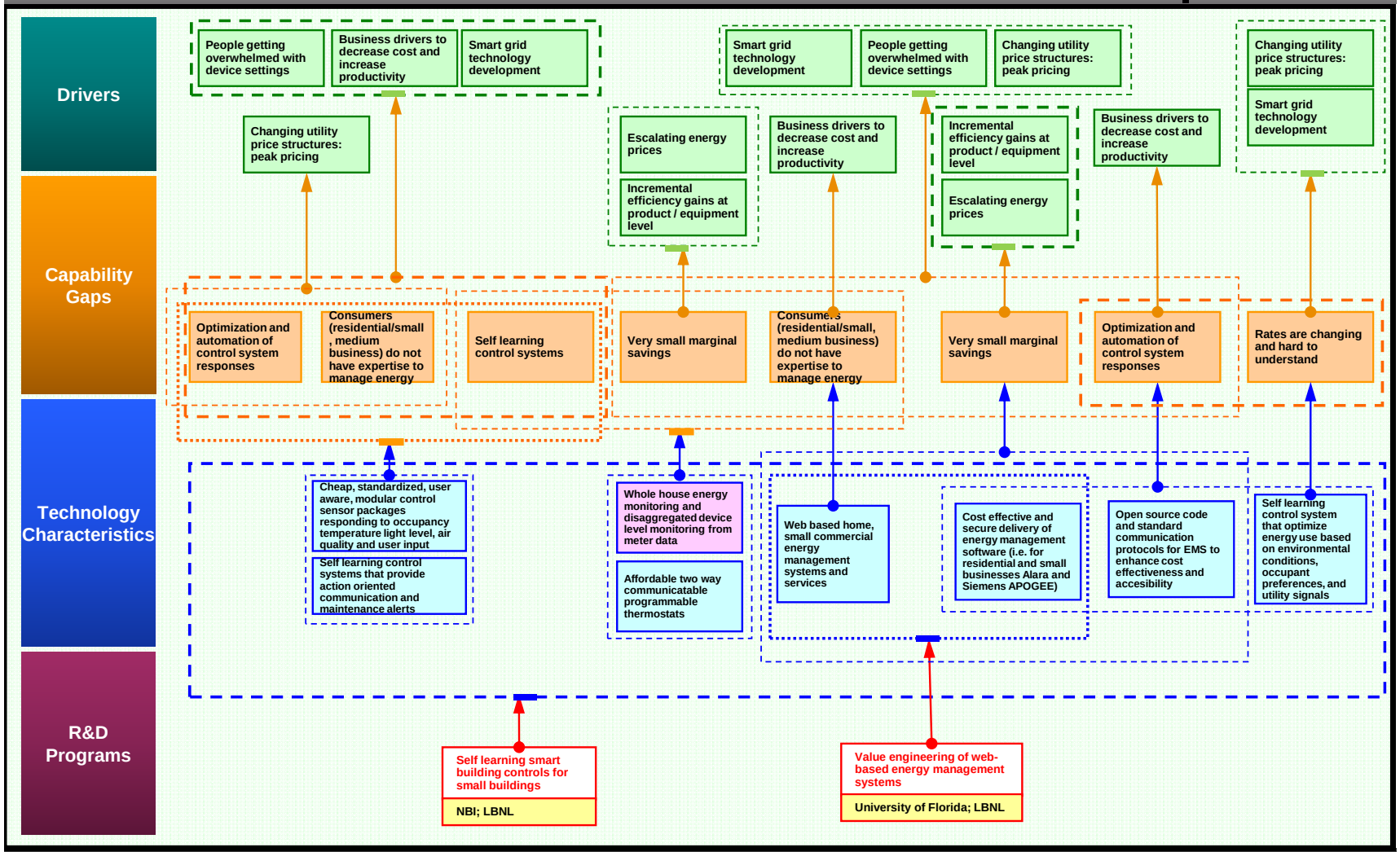
1. Questions not yet specified.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Energy Management Services (4 of 4)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Self learning smart building controls for small buildings. Develop, test and deploy technology that allows customers, utilities and service providers to optimize building operation with little if any technical expertise and engagement.

Existing research: New Buildings Institute (NBI), Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

1. What human interface is needed?
2. What types of sensors are needed?
3. What are the analytic protocols to make learning work?
4. What level of automation is needed now and in the future?
5. How is optimization achieved?
6. Notification protocols?

Value engineering of web-based energy management systems. Examine the cost structure of energy management systems to identify levers to pull to reduce costs. For example, if sensors are a key barrier to cost effectiveness how can these costs be brought down?.

Existing research: University of Florida, Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

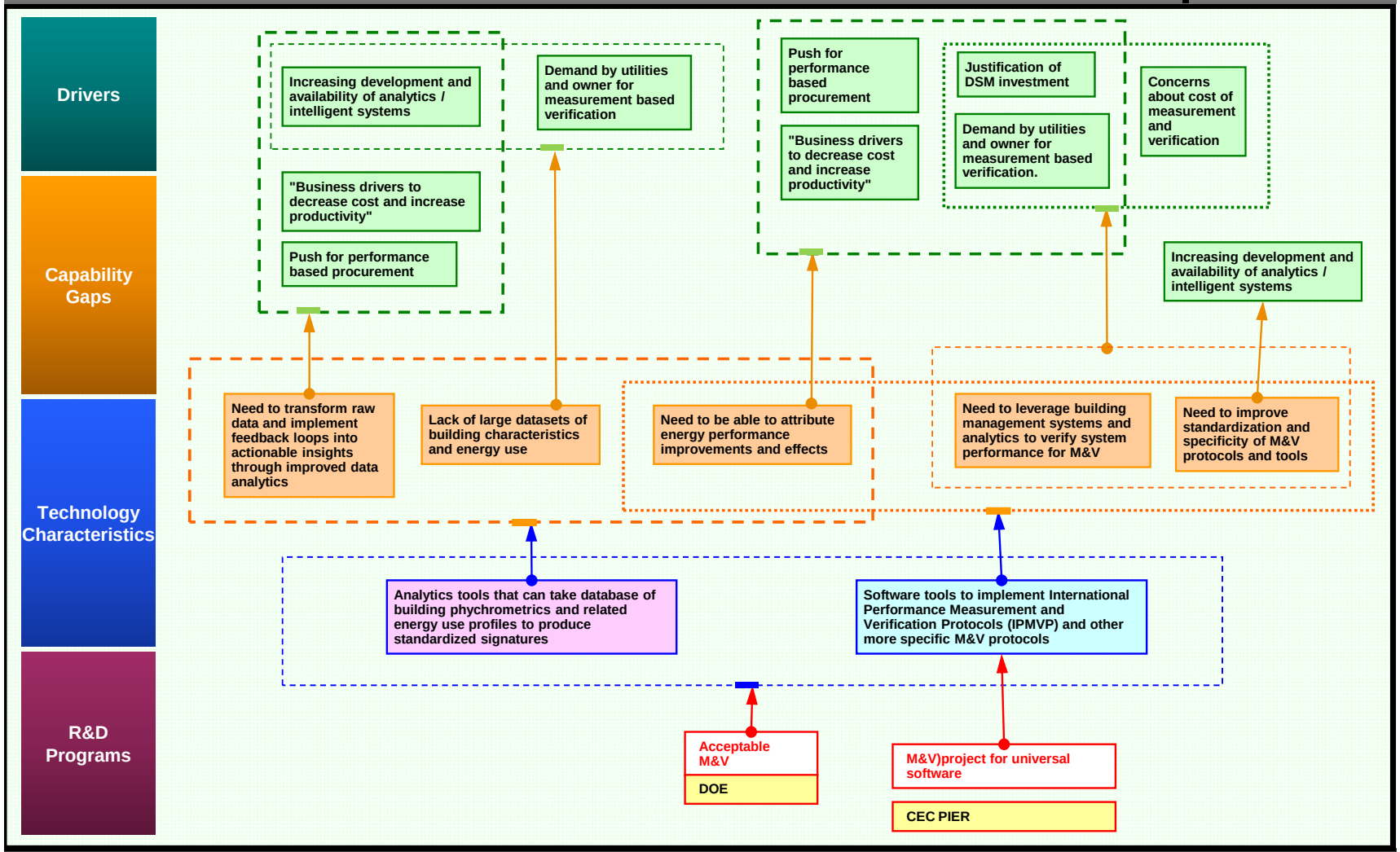
1. What elements of systems are key drivers of cost?
2. Can these drivers be influenced by technology advances?
3. What additional research should be done to reduce costs?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Low-Cost Savings Verification Techniques (1 of 7)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

M&V project for universal software. Universal software protocol for monitoring and verification (M&V) would increase the reliability of measurements from complex systems, simplify implementation, and reduce costs for savings verification procedures.

Existing research: California Energy Commission (CEC) Public Interest Energy Research (PIER) program.

- The CEC PIER program is currently working on that makes use of Pacific Gas & Electric's Universal Translator tool; see Appendix B for more information.

Key research questions:

1. Questions not yet specified.

Acceptable M&V. (Summary not yet provided.)

Existing research: U.S. Department of Energy (DOE) Uniform Methods Project.

- *[Summaries of existing research pending]*

Key research questions:

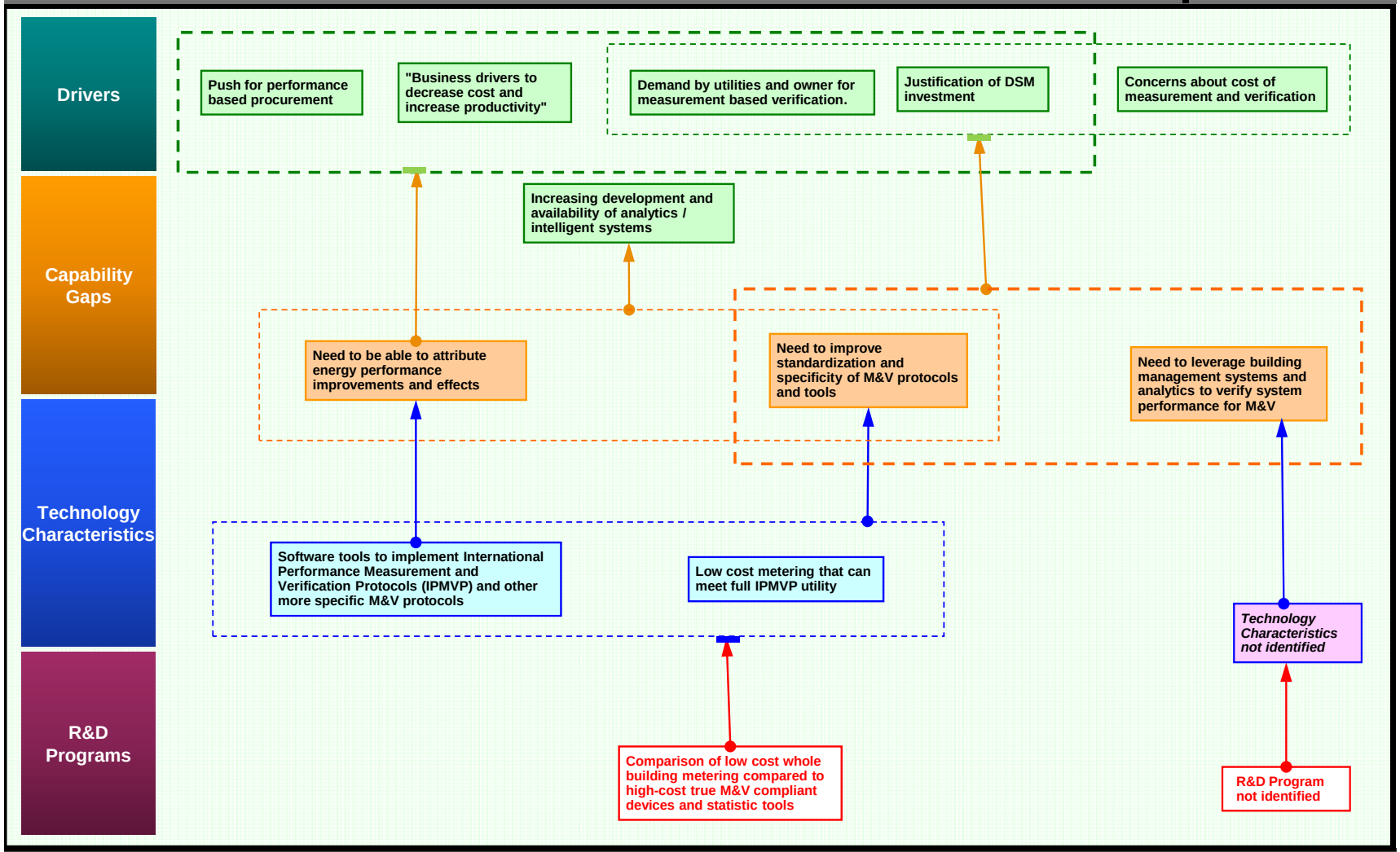
1. Questions not yet specified.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Low-Cost Savings Verification Techniques (2 of 7)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

Comparison of low cost whole building metering compared to high-cost true M&V compliant devices and statistic tools. There are numerous approaches electric bill disaggregation with varying cost and accuracy.

Existing research: None identified.

Key research questions:

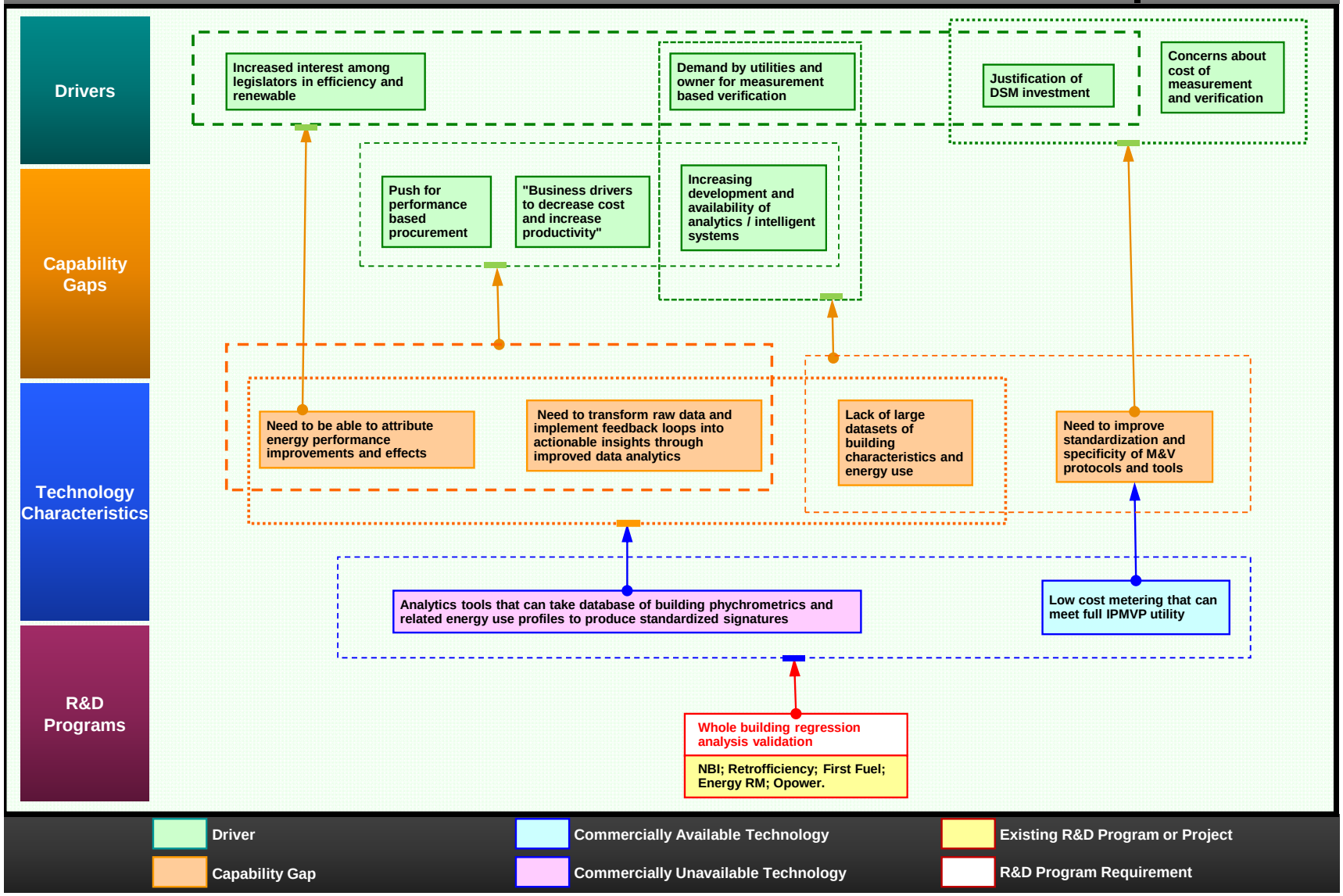
1. What approaches or hybrid methods can be used for different contexts?
2. Is amp only metering drastically different from true power metering?
3. Is true cost of International Performance Measurement and Verification (IPMVP) compliance worth it?
4. Comparison of measuring/modelling tools:
    a. Low cost data logging;
    b. statistical analysis;
    c. revenue quality metering;
    d. variance in accuracy; and
    e. cost effectiveness.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Low-Cost Savings Verification Techniques (3 of 7)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Whole building regression analysis validation. Validation of multi fuel engineering based regression analysis to show whole building energy use by end-use. The primary target is commercial buildings. Focus is on standardization of signatures of routine and non-routine changes.

Existing research: New Buildings Institute (NBI), Retrofficiency, First Fuel, Energy RM, Opower.

- *[Summaries of existing research pending]*

Key research questions:

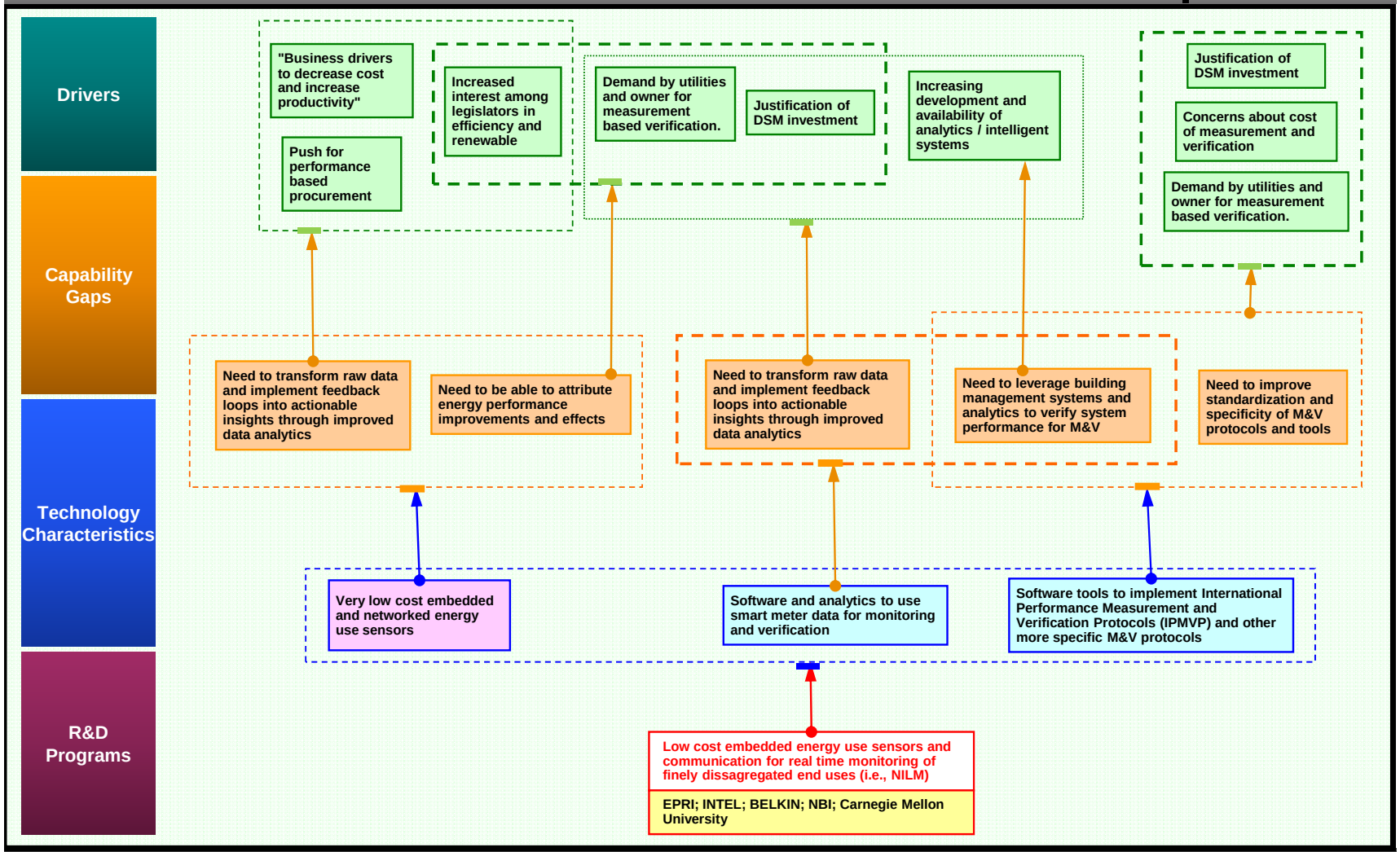
1. What level of accuracy can be achieved by this method?
2. how well can routine and non-routine changes in buildings be identified and quantified?
3. can the method achieve the 10x reduction in M&V cost needed to open the market?
4. what is being done currently and by whom?
5. How much is the R&D is public domain Vs. private?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Low-Cost Savings Verification Techniques (4 of 7)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Low cost embedded energy use sensors and communication for real time monitoring of finely disaggregated end uses. Embedding energy use sensors and communication into all energy using equipment by OEMS will provide the scale to drive down the price of end use metering, utilizing real time communications enables as needed low cost monitoring (for example, non-intrusive load monitoring (NILM)).

Existing research: Electric Power Research Institute (EPRI), Intel, Belka, University of Washington, Carnegie Mellon University, New Buildings Institute (NBI).

- *[Summaries of existing research pending]*

Key research questions:

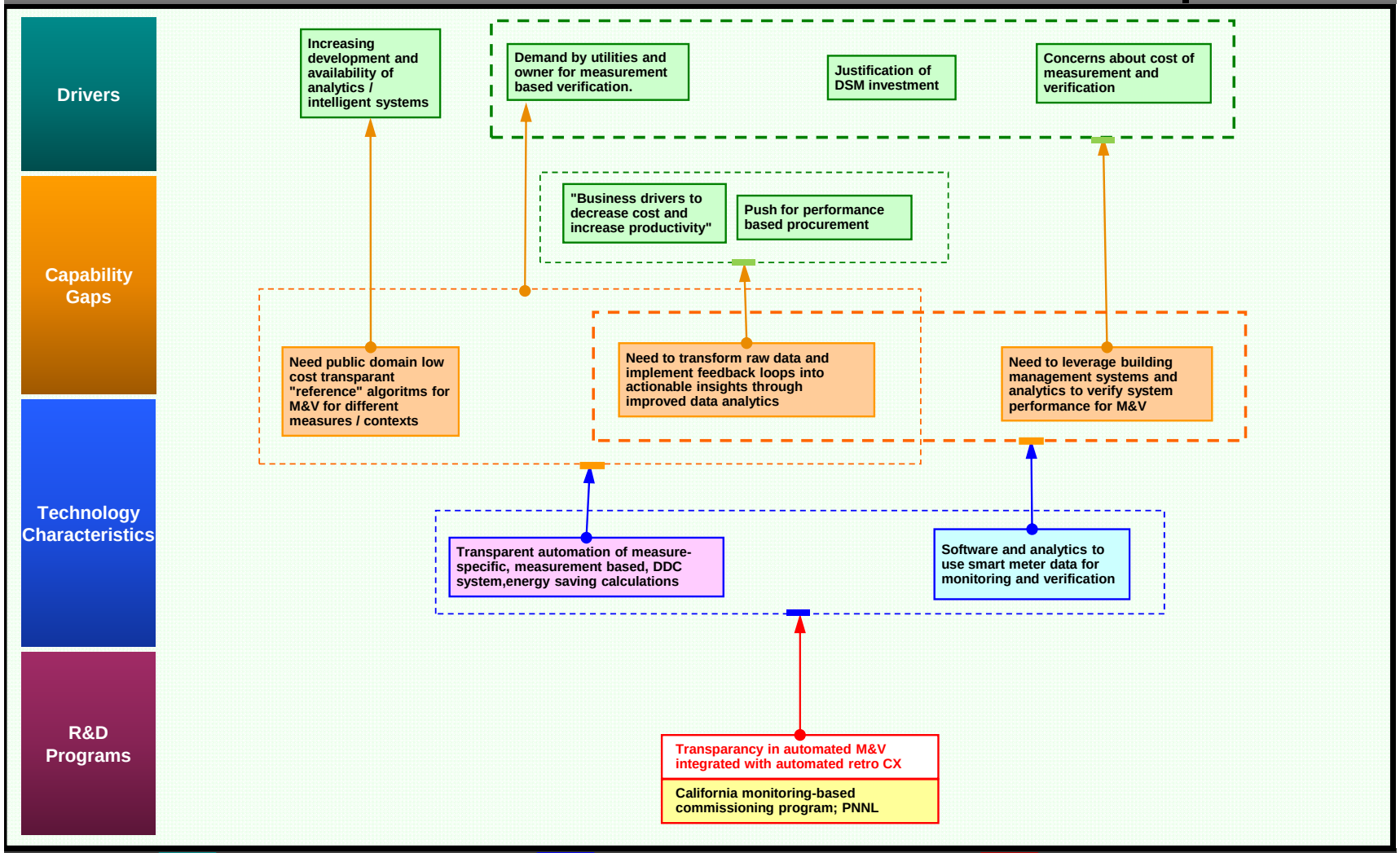
1. Develop low cost, small kw sensors with integrated communication chips.
2. Develop communication systems and protocols for standardized reporting
3. can we drive the equipment and transaction cost so low that OEMs will want to integrate into their products.
4. How does this energy info system integrate into building controls?
5. what standards and protocols are needed to communicate, what the devise is, where it is.
6. Are the advantages to including other sensors such as pressure temp occupancy etc?
7. should higher level efficiency meterics be incorporated into sensor bundle?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Low-Cost Savings Verification Techniques (5 of 7)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Transparency in automated M&V integrated with automated retro commissioning.

Identify DDC system points to monitor efficiency increase to valc [?].

Existing research: California monitoring-based commissioning program, Pacific Northwest National Laboratory (PNNL)returning projects.

- *[Summaries of existing research pending]*

Key research questions:

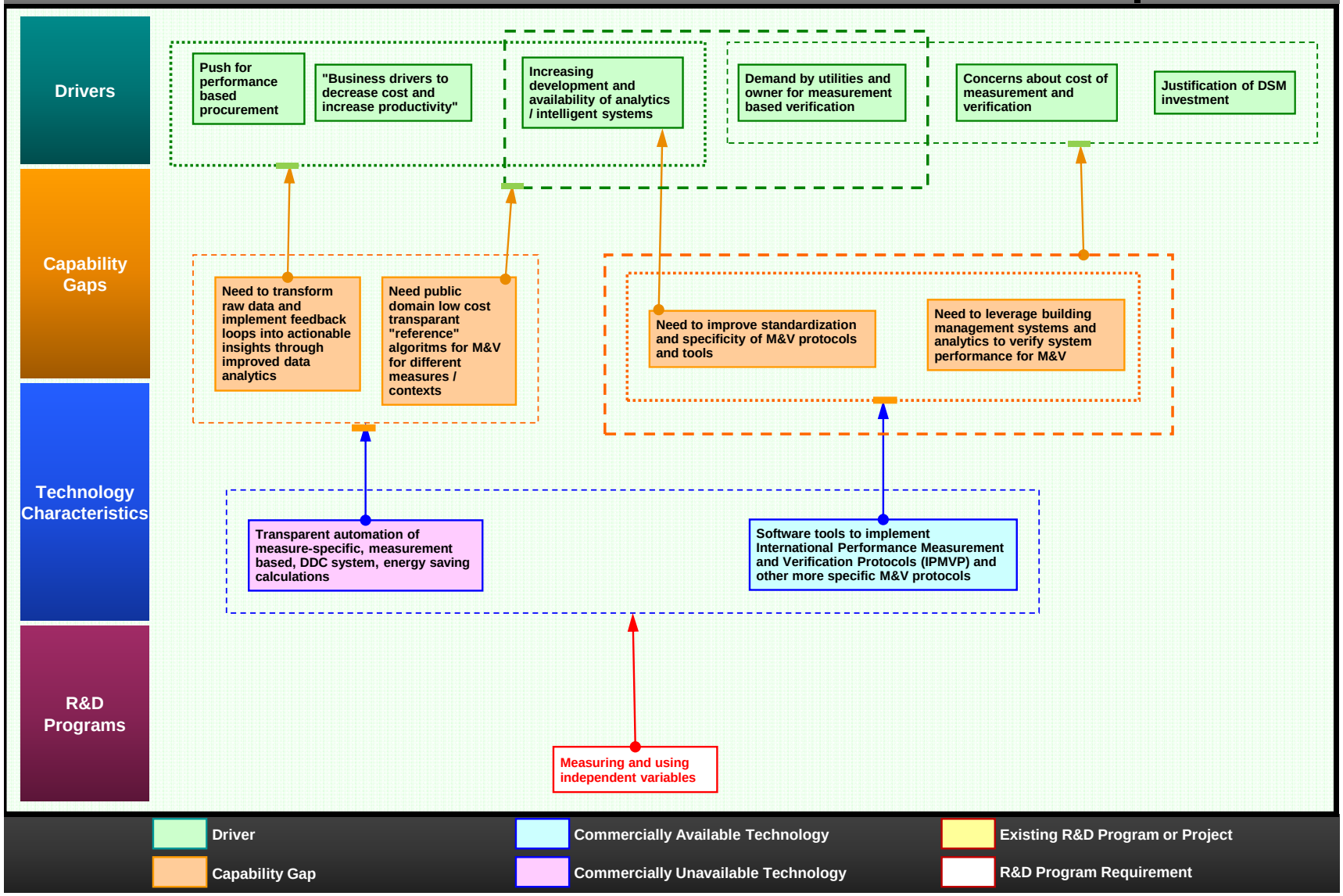
1. How to quantify system based on baseline and past installation direct digital controller (DDC) building automation systems (BAS) trends?
2. How to create permanent efficinecy index?
3. How to provide online documentation?
4. How to trend data without slowing down control?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Low-Cost Savings Verification Techniques (6 of 7)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

Measuring and using independent variables. Develop methods to better utilize independent variable.

Existing research: None identified.

Key research questions:

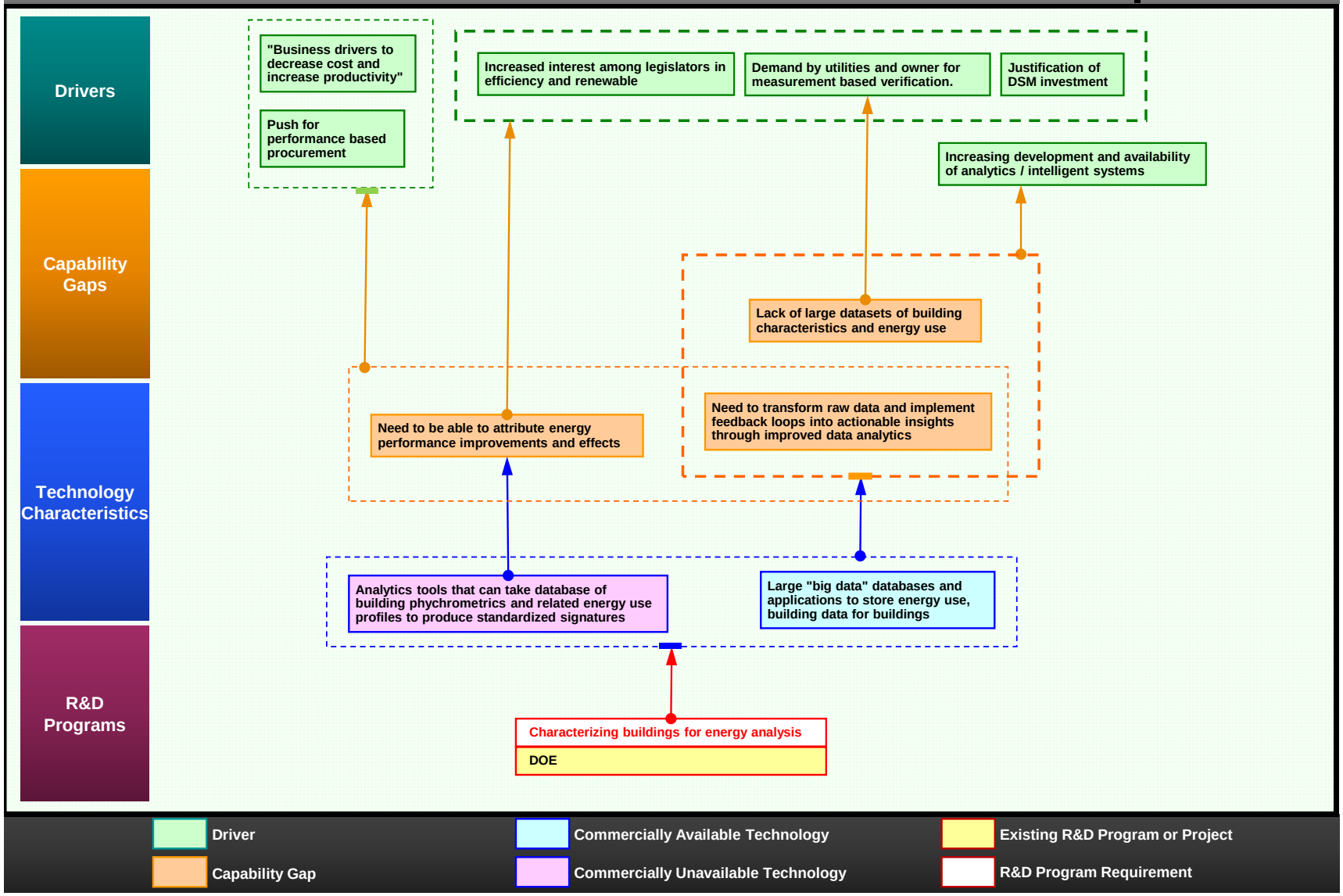
1. What independent variables can be used as proxies for energy (e.g. variable frequency drive (VFD) speed as proxy for KW?)
2. What are the key independent variables for important energy efficiency measures?
3. can these independent variables be monitored independently in the field and then combined with lab test (of energy use as a function of these field measured independent variables)?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Low-Cost Savings Verification Techniques (7 of 7)**

See "Technology Area Definitions" section



R&D Program Summaries

Characterizing buildings for energy analysis. Naked energy data without context has limited value. Need to understand building and usage characteristics and do this at very low cost.

Existing research: U.S. Department of Energy (DOE)-building performance database.

- DOE: Buildings Performance Database, https://www1.eere.energy.gov/buildings/commercial/bpd.html.

Key research questions:

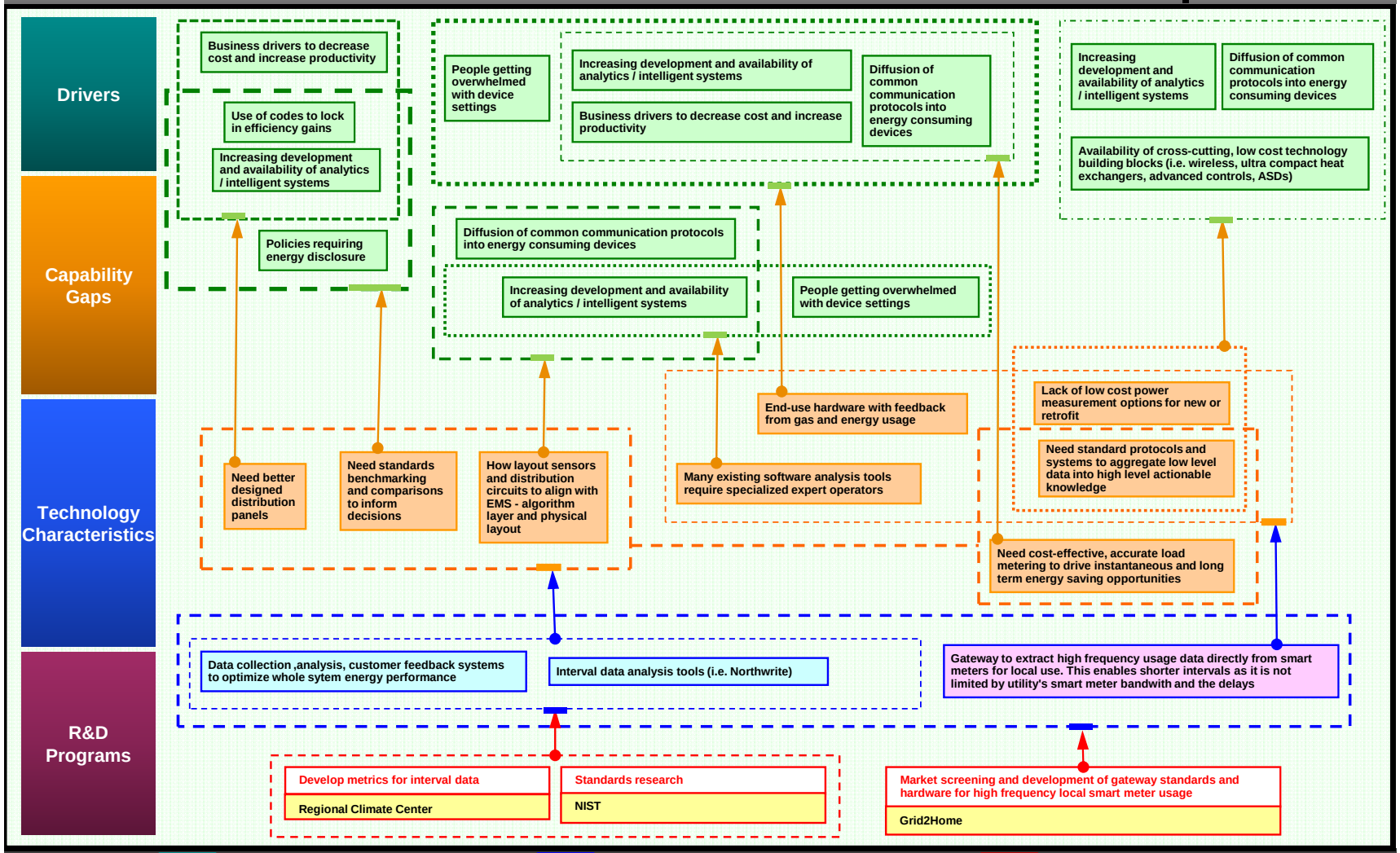
1. What information could be gathered with the "ideal" meter?
2. How do we affordably characterized buildings in term of construction HVAC so we can design smart retrofit program?
3. Can we create standard taxonomy for building system and components?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Real time smart electric power measurement of facilities (1 of 3)**

See "Technology Area Definitions" section



R&D Program Summaries

Standards research. Developing standards for measuring facility energy use would help simplify and standardize energy measurement. Work with NIST priority action group to help develop useful standards.

Existing research: National Institute of Standards and Technology (NIST).

- *[Summaries of existing research pending]*

Key research questions:

1. Is there a universal metric that can be applied to all sectors?
2. How does the cost of the measurement compare to the value?

Develop metrics for interval data. Related to significant drivers such as time of day, weather etc., high/low ratios. The first step to analyzing energy use is good data. Developing standardized metrics will help make the information more accessible and make it easier for more people to be able to analyze the data.

Existing research: Regional Climate Center.

- *[Summaries of existing research pending]*

Key research questions:

1. What type of meter sensing is needed for what size businesses?
2. How can this information be shared and leveraged?
3. Who is responsible and what quality data is required?

Market screening and development of gateway standards and hardware for high frequency local smart meter usage. This program will enable customers to capture and react to high frequency data from existing utility smart meters by accessing local channels rather than going through the utility cloud.

Existing research: Grid2Home.

- *[Summaries of existing research pending]*

Key research questions:

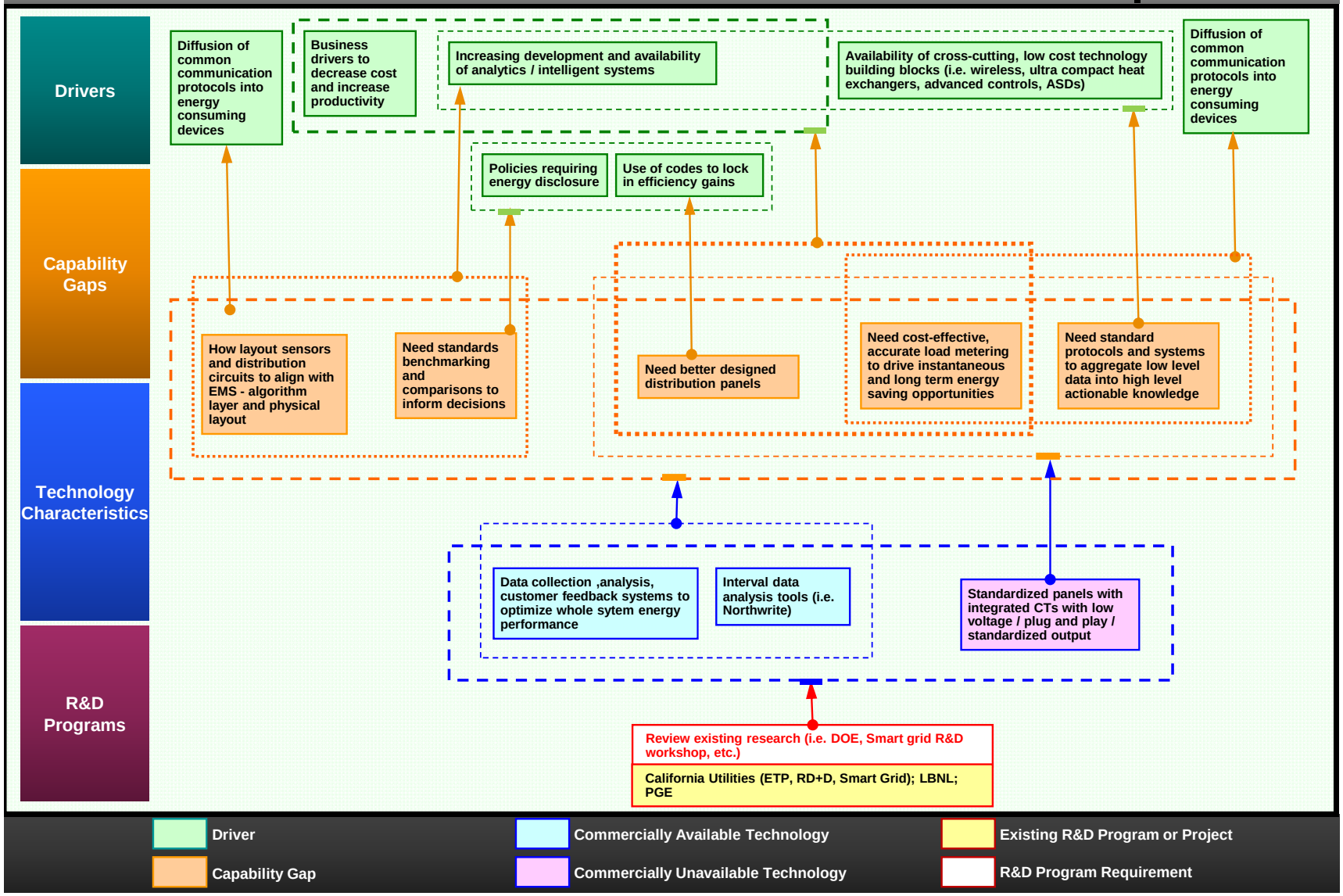
1. Screen existing smart meter market and identify availability and protocols for local ports / channels that can provide smart meter interval data directly to the customer.
2. Develop standards for communicating and organizing this data.
3. Develop hardware that will access, store and present this data to customers directly.
4. Provide access to this database for third parties. (e.g. disaggregators, auditors) to use this data for analytics.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Real time smart electric power measurement of facilities (2 of 3)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Review existing research (i.e. DOE, Smart grid R&D workshop, etc.). To develop continuously updated database of existing technologies to include characteristics such as; building size, building type, frequency of data, number of installations, stage of technology development, local compared to cloud, analytics compared to no analytics, software compared to no software, control compared to no control.

Existing research: California Utilities (ETP, RD+D, Smart Grid), Lawrence Berkeley National Laboratory (LBNL), Portland General Electric (PGE).

- *[Summaries of existing research pending]*

Key research questions:

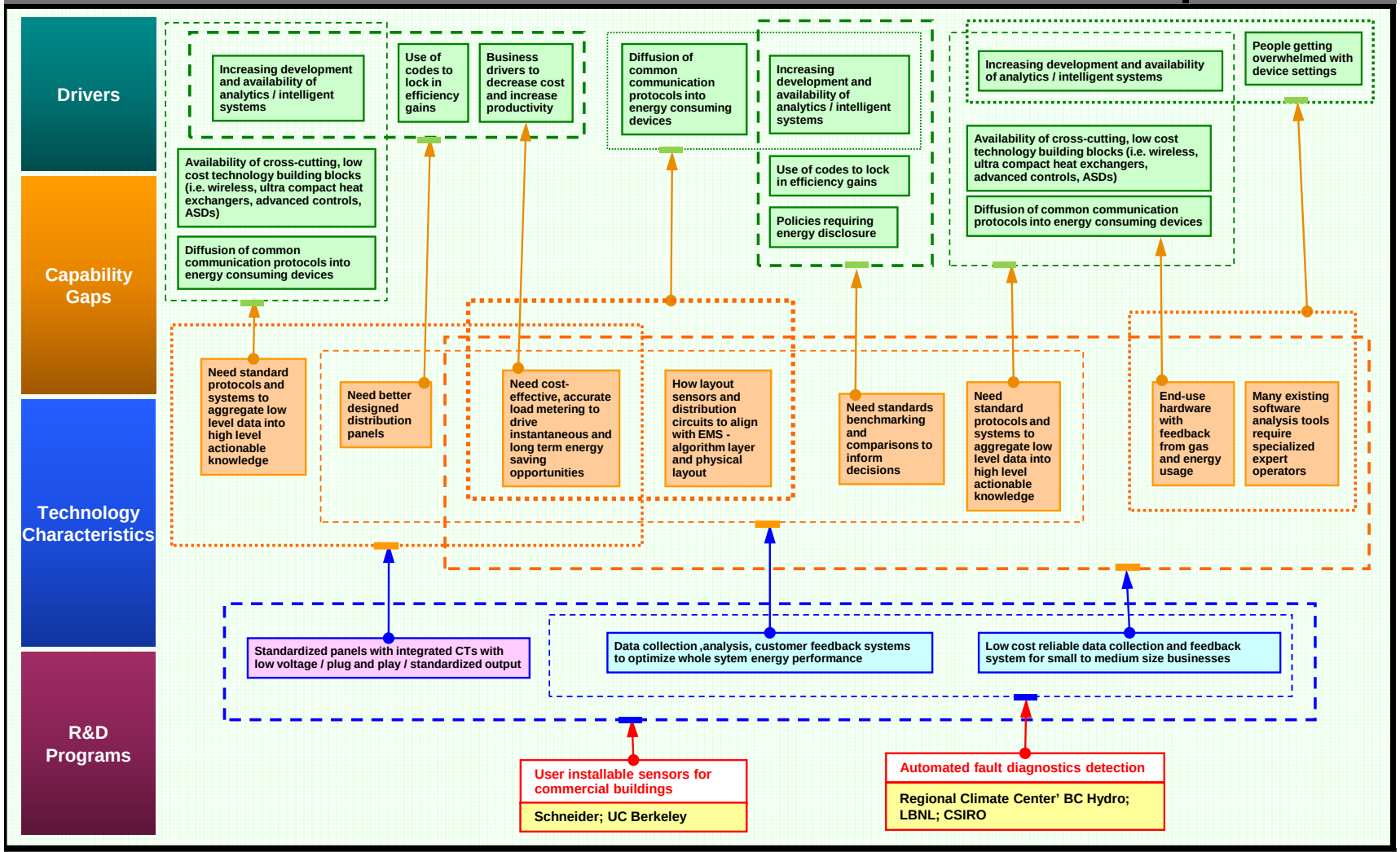
1. Populate database based on existing technologies.
2. Maintain this database continuously for X years through outreach and regular market screening efforts.
3. Proactively distribute and measure use of this database accordingly to key players.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Real time smart electric power measurement of facilities (3 of 3)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

User-installable sensors for commercial buildings. M&V diagnostics and efficiency require monitoring that is load specific and inexpensive to install. Research is needed for systems that can be safely and quickly installed to collect critical metrics.

Existing research: Schneider, University of California Berkeley.

- *[Summaries of existing research pending]*

Key research questions:

1. What sensing technology would be suitable as a low/no cost add-on for circuit breaker panels?
2. How can voltage be measures on multiple phases without needing an electrician to install loads?
3. Can a low voltage connector be added to new breakers or meters that allow for high bandwidth metering (8kHz) for fault diagnostics and load disaggregation?

Automated fault diagnostics detection. Fault diagnostics to auto detect opportunities by leveraging existing data collection.

Existing research: BC Hydro, Regional Climate Center, Commonwealth Scientific and Industrial Research Organisation (CSIRO).

- *[Summaries of existing research pending]*

Key research questions:

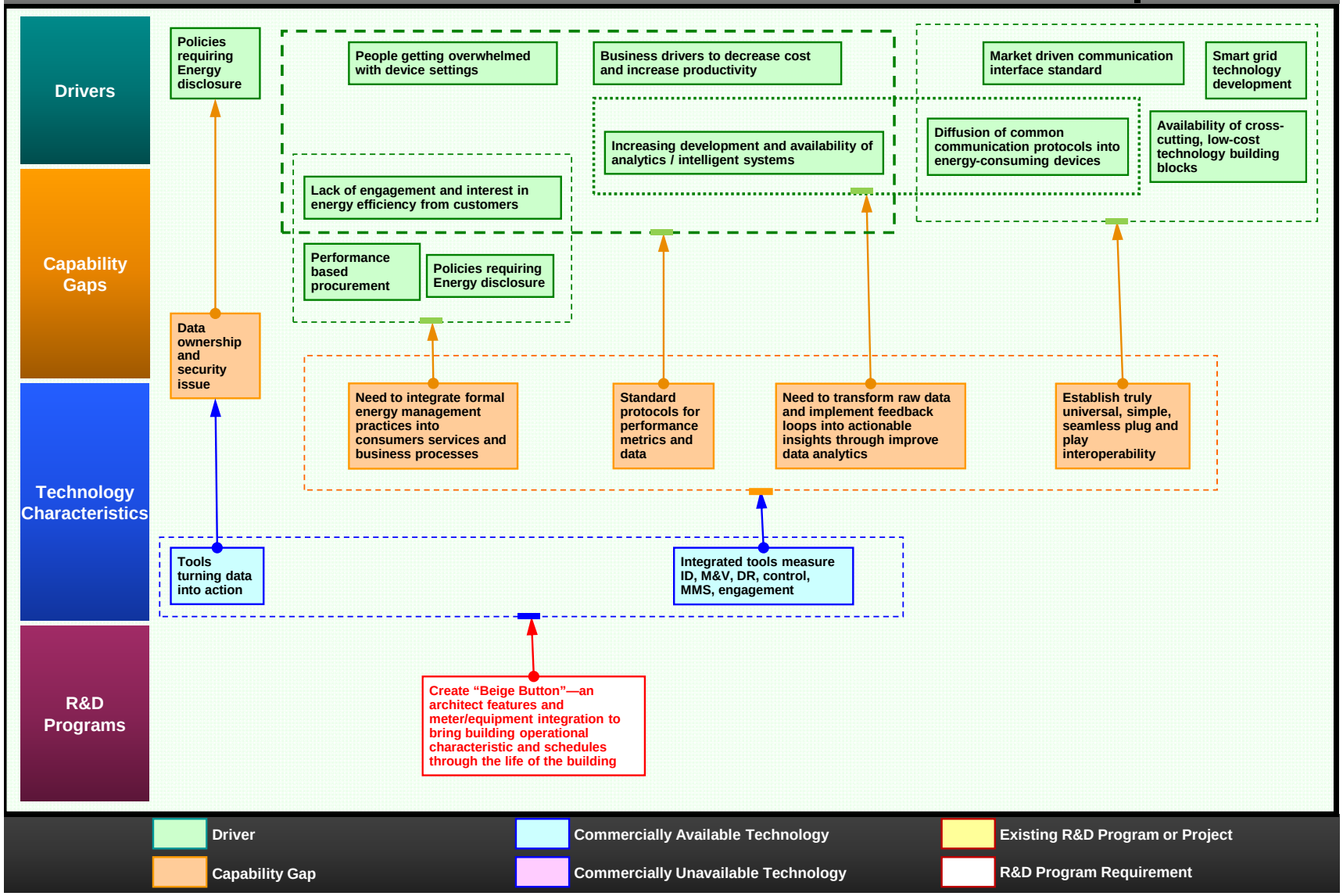
1. Can we help end use customers (by way of evaluation tools) to gauge which fault detection (FD) products are suited for their needs?
2. Guide sophistication of fault detection (FD) products to get to the point where they pin-point a problem and recommend a fix action?
3. Can fault detection (FD) product performance be standardized?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Enterprise and Maintenance Management Systems (1 of 9)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

Create "Beige Button"—architect features and meter/equipment integration to bring building operational characteristic and schedules through the life of the building.

Integrating physical features (assumed energy simulation models), operational assumptions, and other characteristics that affect performance and link them to meters/equipment for full picture of whole buildings and portfolios.

Existing research: None identified.

Key research questions:

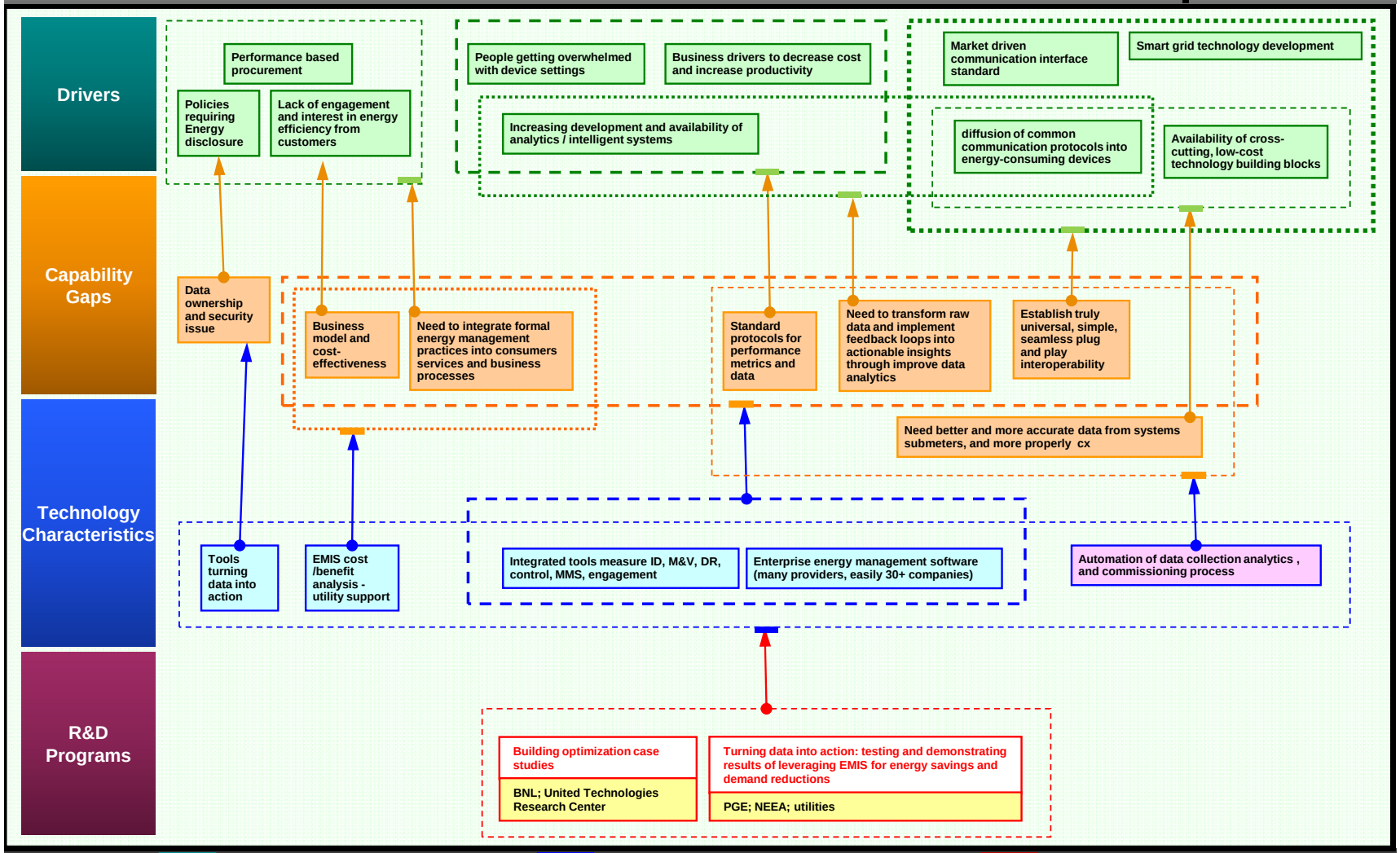
1. Does any toll currently track all these?
2. How to integrate hard architecture vs. fast moving technology software?
3. Prevent silos.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Enterprise and Maintenance Management Systems (2 of 9)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Turning data into action: testing and demonstrating results of leveraging EMIS for energy savings and demand reductions. Utilities across the country are interested in achieving O&M and behavioral savings for commercial buildings through utilizing technology. But no one really knows which approaches are the most effective in turning ubiquitous data into action. This research project will examine average savings from case studies and demonstrations of different EMIS applications to more specifically determine expected energy saving results.

Existing research: Portland General Electric (PGE), Northwest Energy Efficiency Alliance (NEEA), utilities across country.

- *[Summaries of existing research pending]*

Key research questions:

1. What percentage savings can we expect from different applications of Energy Management Information Systems (EMIS) and do these savings persist (or how can we ensure they persist)?
    a. Behavior / competition (behavior only).
    b. Monitoring-based commissioning (operations and maintenance plus retrofit).
    c. Energy coaching.

Building optimization case studies. Need for independent data based and technically valid (IMPU) studies to validate and document actual savings achieved. Too many self-savings "claimed" results.

Existing research: Brookhaven National Laboratory (BNL), United Technologies Research Center (UTRC).

- *[Summaries of existing research pending]*

Key research questions:

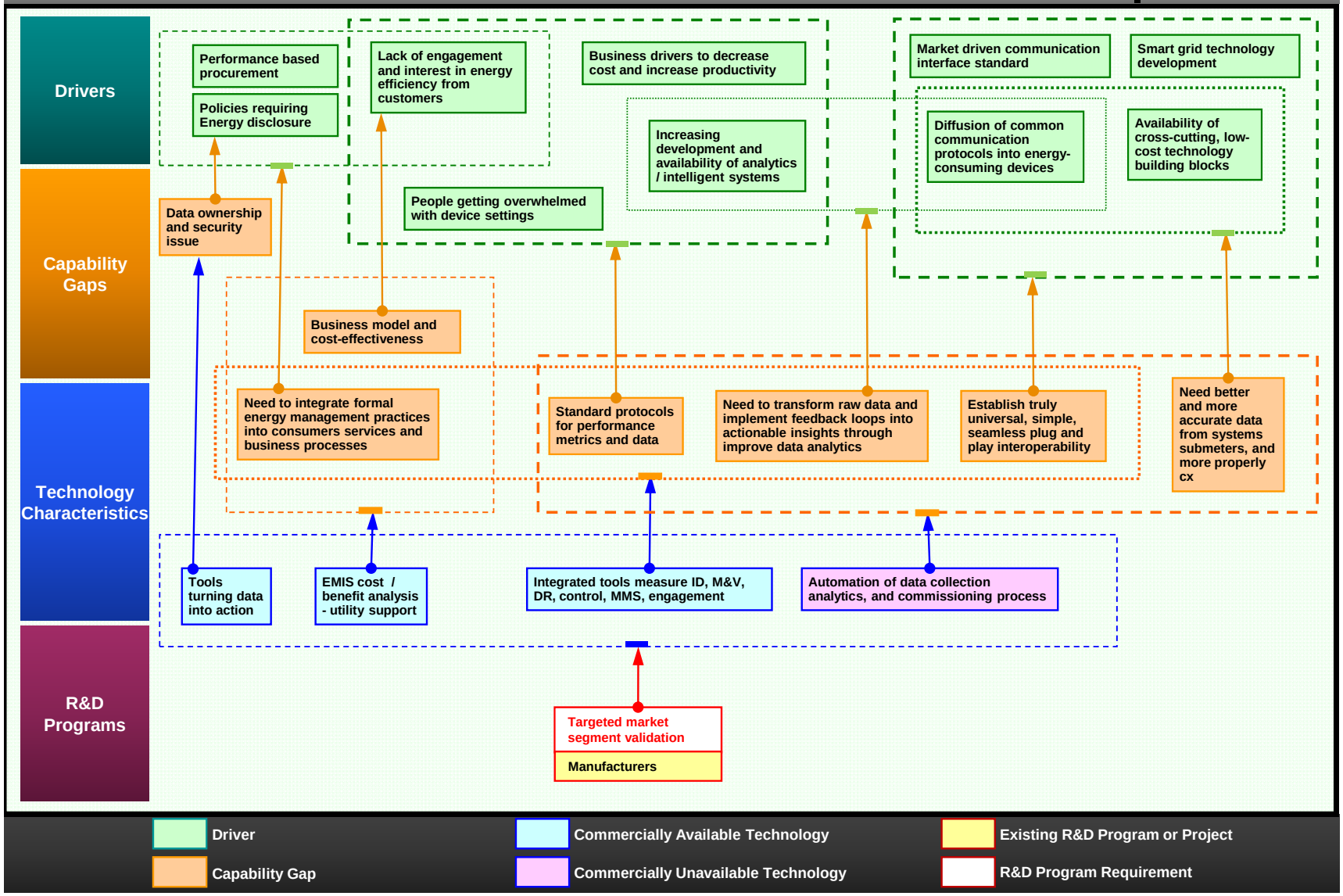
1. Base line energy use.
2. Identify all projects and operational changes.
3. Adjust for weather, seasonality, independent business changes.
4. Determine actual implementation costs.
5. Determine actual achieved savings.
6. Calculate achieved return on investment as forecasted.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Enterprise and Maintenance Management Systems (3 of 9)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Targeted market segment validation. Prioritize key building type/market segments to test and validate energy analytic tools. Focus on limited building types will allow focused analytic development rather than trying to do everything.

Existing research: Manufacturers.

- *[Summaries of existing research pending]*

Key research questions:

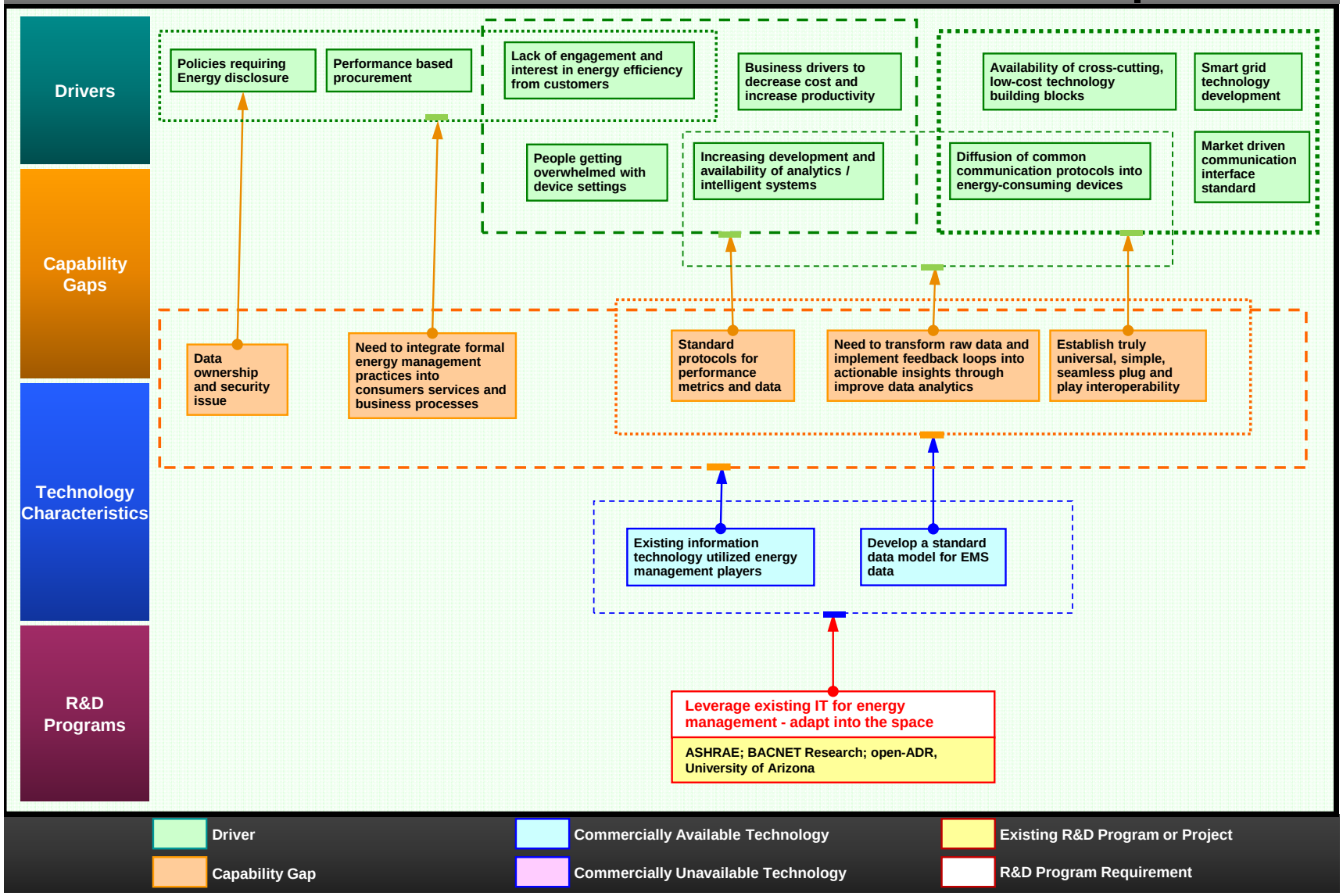
1. How well does analytics model actual building energy use/performance?
2. How well does model identify savings opportunities?
3. How well do predicted savings match forecasted?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Enterprise and Maintenance Management Systems (4 of 9)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Leverage existing IT for energy management - adapt into the space. Leverage existing information technologies (IT) such as ethernet, XML, etc., so as to not inventing anything.

Existing research: American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), BACNET Research, open-ADR, University of Arizona.

- University of Arizona: Autonomic Computing Laboratory, http://acl.ece.arizona.edu/.
- *[Summaries of existing research pending]*

Key research questions:

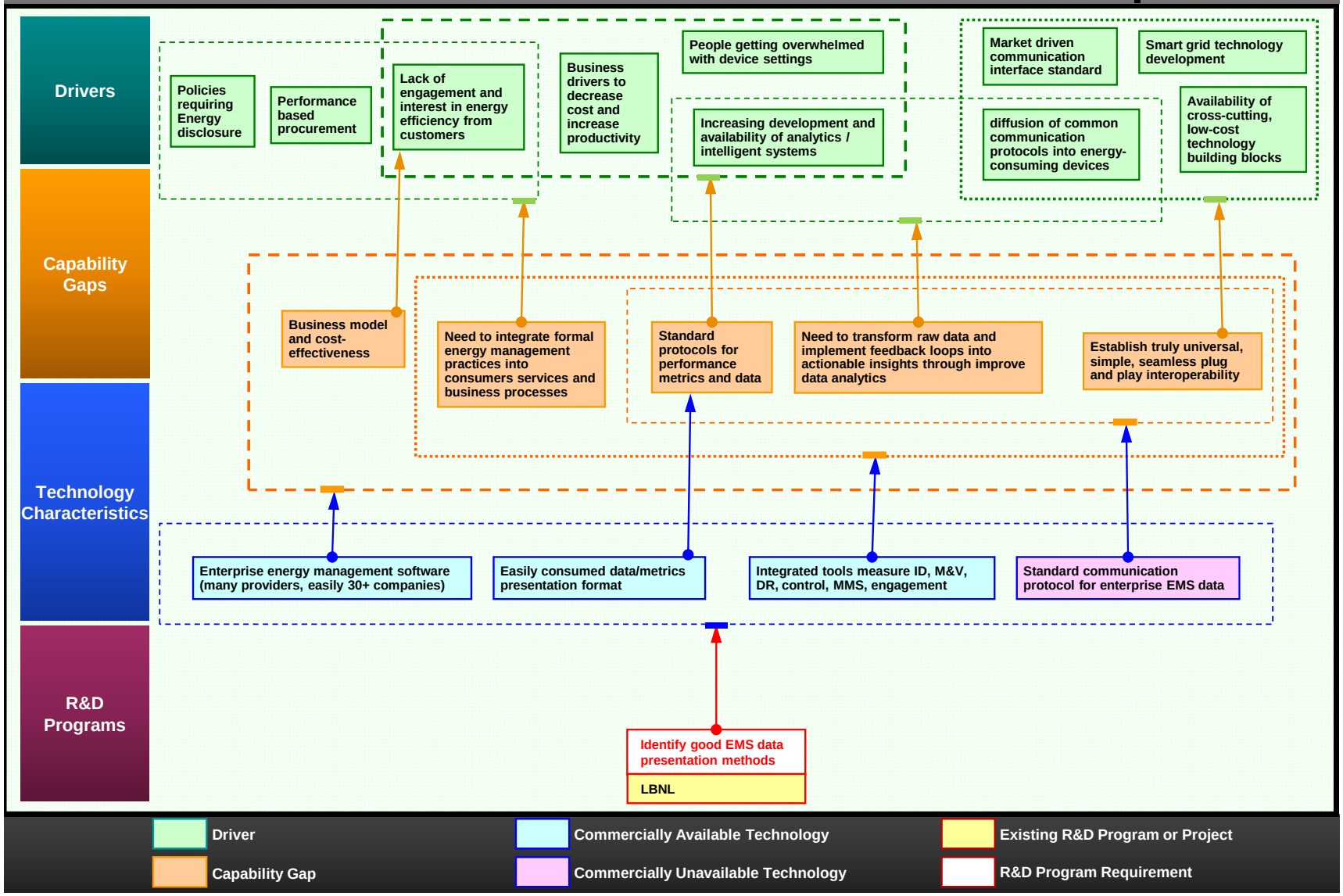
1. Standardized data models protocols.
2. Define consistent performance metric definitions and benchmarking data.
3. Protocols still allowing proprietary systems—effect interoperability.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Enterprise and Maintenance Management Systems (5 of 9)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Identify good EMS data presentation methods. Data and form of presentations (user interface design).

Existing research: Lawrence Berkeley National Laboratory (LBNL).

- *[Summaries of existing research pending]*

Key research questions:

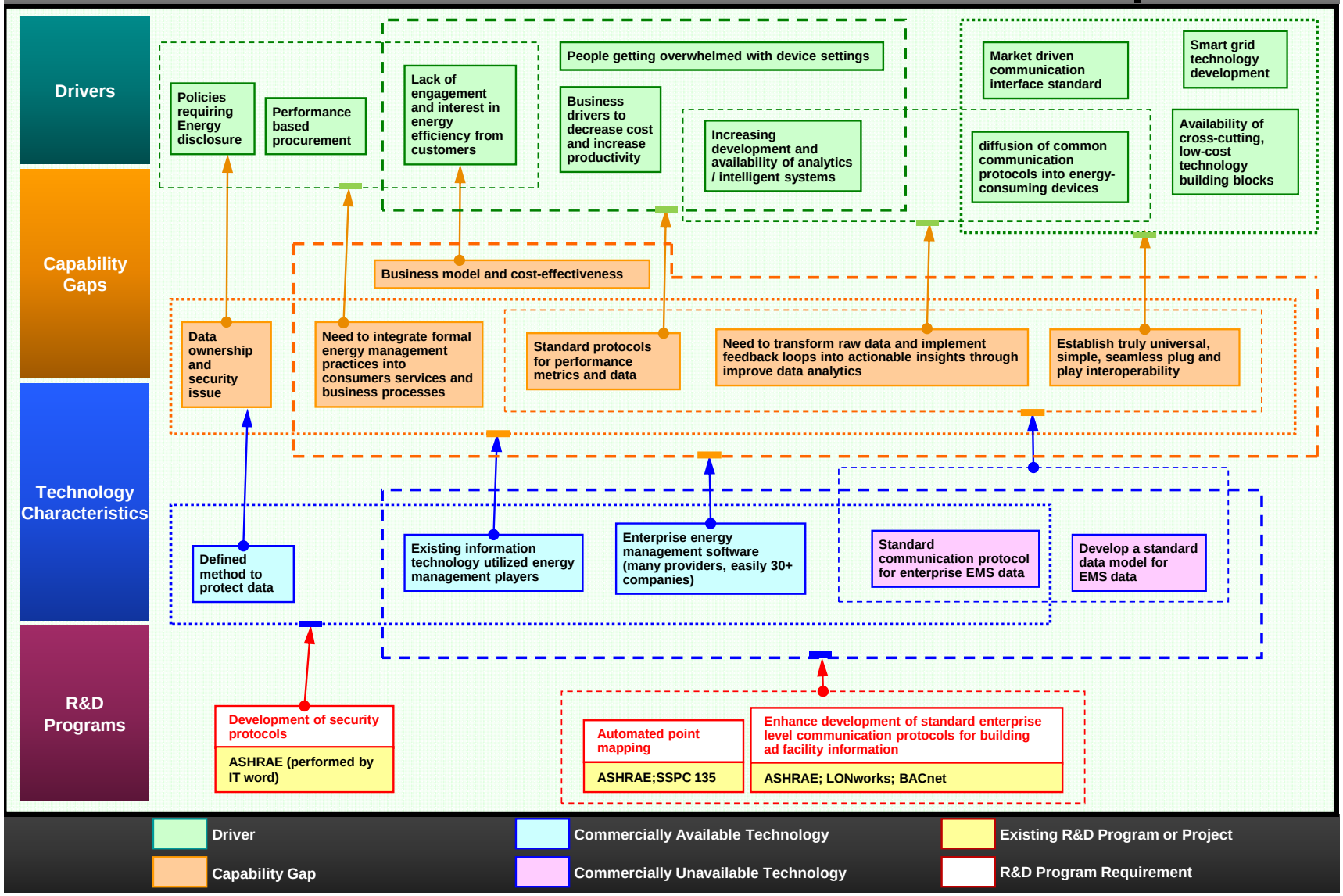
1. What data is most relevant for an energy management?
2. What forms should EMS data and analytics be presented to user?
3. What data expression forms are best suited for identifying?
4. Review current market and tools.
5. Relate presentation form/data to target actions.
6. Energy savings outcomes of different programs designs.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Enterprise and Maintenance Management Systems (6 of 9)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Development of security protocols. In developing and promulgating enterprise energy management systems, it is very desirable to standardize protocols for multiple reasons, including ways to communicate with a central system and for security.

Existing research: Stakeholders indicate that the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) is working on this (through IT word).

- *[Summaries of existing research pending]*

Key research questions:

1. What are agreed protocols for security?
2. How data gets used and who owns it?

Automated point mapping. Inaction often results from data provided by enterprise energy and maintenance systems because the gathered data and inaccurate. This data is incorrect because point mapping (assign a variable name and description to a measurement point methods an enterprise energy and maintenance management system) is manual, tedious and error prone process.

Existing research: ASHRAE, SSPC 135.

- *[Summaries of existing research pending]*

Key research questions:

1. Are there semi-automated process to improve point mapping?
2. Are there semi-automated pathways to perform quality assurance (QA) / quality control (QC)steps for the point mapping process?
3. Are there ways to automate point mapping?

Enhance development of standard enterprise level communication protocols for building ad facility information. Bacnet, Obix and other communication effort are improving greatly, but there are key aspects that are not being addressed by these standards bodies.

Existing research: American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), LONworks, BacNet.

- *[Summaries of existing research pending]*

Key research questions:

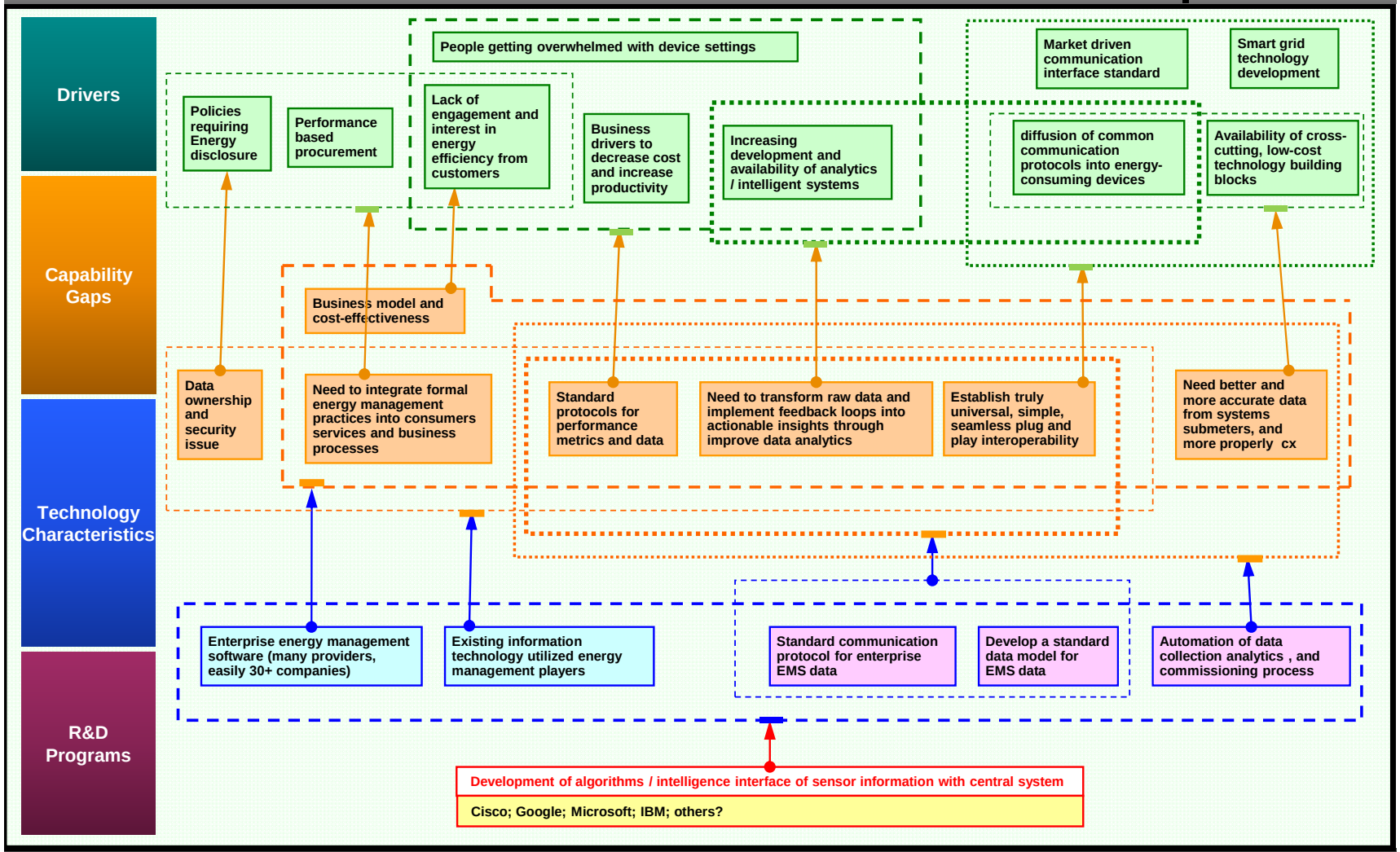
1. Can details, satirized point mapping (Assign a variable name and description to a measurement point within an enterprise energy and maintenance management system) occur and be supported by existing enterprise level communication standards for building and facility information?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Enterprise and Maintenance Management Systems (7 of 9)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Development of algorithms / intelligence interface of sensor information with central system. In developing and promulgating enterprise energy management systems, it is very desirable to standardize protocols for multiple reasons, including ways to communicate with a central system.

Existing research: Many programs and enterprises are working on this, including Cisco, Google, IBM, Microsoft, and others; ongoing research from private firms tends largely to be proprietary and, therefore, not thoroughly or consistently reported through companies' web pages.

- Some information about the work of Microsoft Research's Sensing and Energy Research Group in this area can be found in Appendix B.

Key research questions:

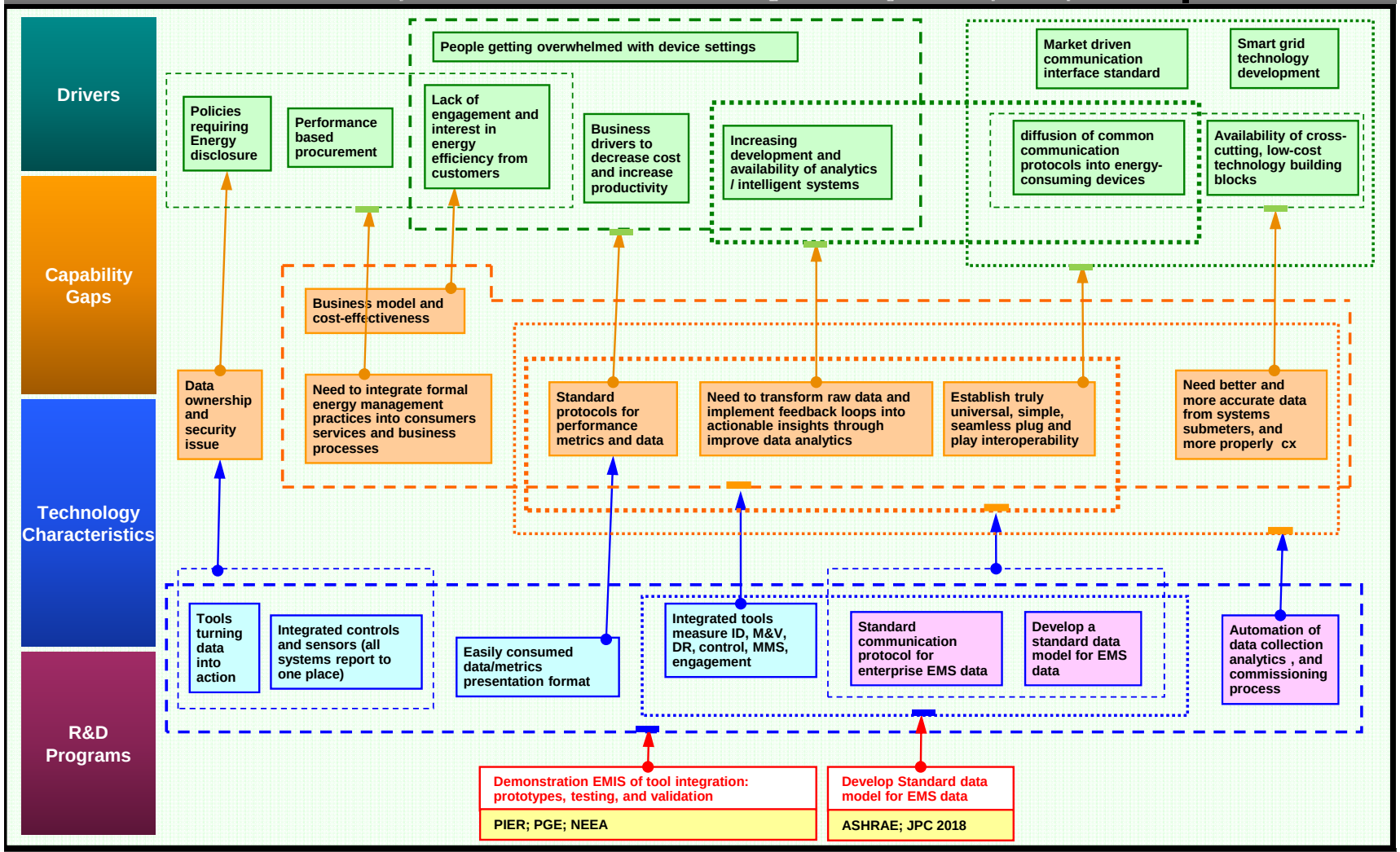
1. Questions not yet specified.

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Enterprise and Maintenance Management Systems (8 of 9)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Develop Standard data model for EMS data. (Summary not yet provided.)

Existing research: American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE), JPC 2018.

- *[Summaries of existing research pending]*

Key research questions:

1. What data do you collect?
2. What format do you provide the data?
3. How do you provide the data?

Demonstration EMIS of tool integration: prototypes, testing, and validation. In commercial energy management and information system software market, there are many functionalities available currently. The future will require integrated solutions that combine EMIS with enabling functions for energy savings, demand response, building control, and M&V. This research project will test integrated prototypes propose by industry (key that research does not need to develop the approaches, but test what is already commercialized), validating the accuracy of the algorithms and capability of approach.

Existing research: California Energy Commission (CEC) Public Interest Energy Research (PIER) program, Portland General Electric (PGE), Northwest Energy Efficiency Alliance (NEEA).

- *[Summaries of existing research pending]*

Key research questions:

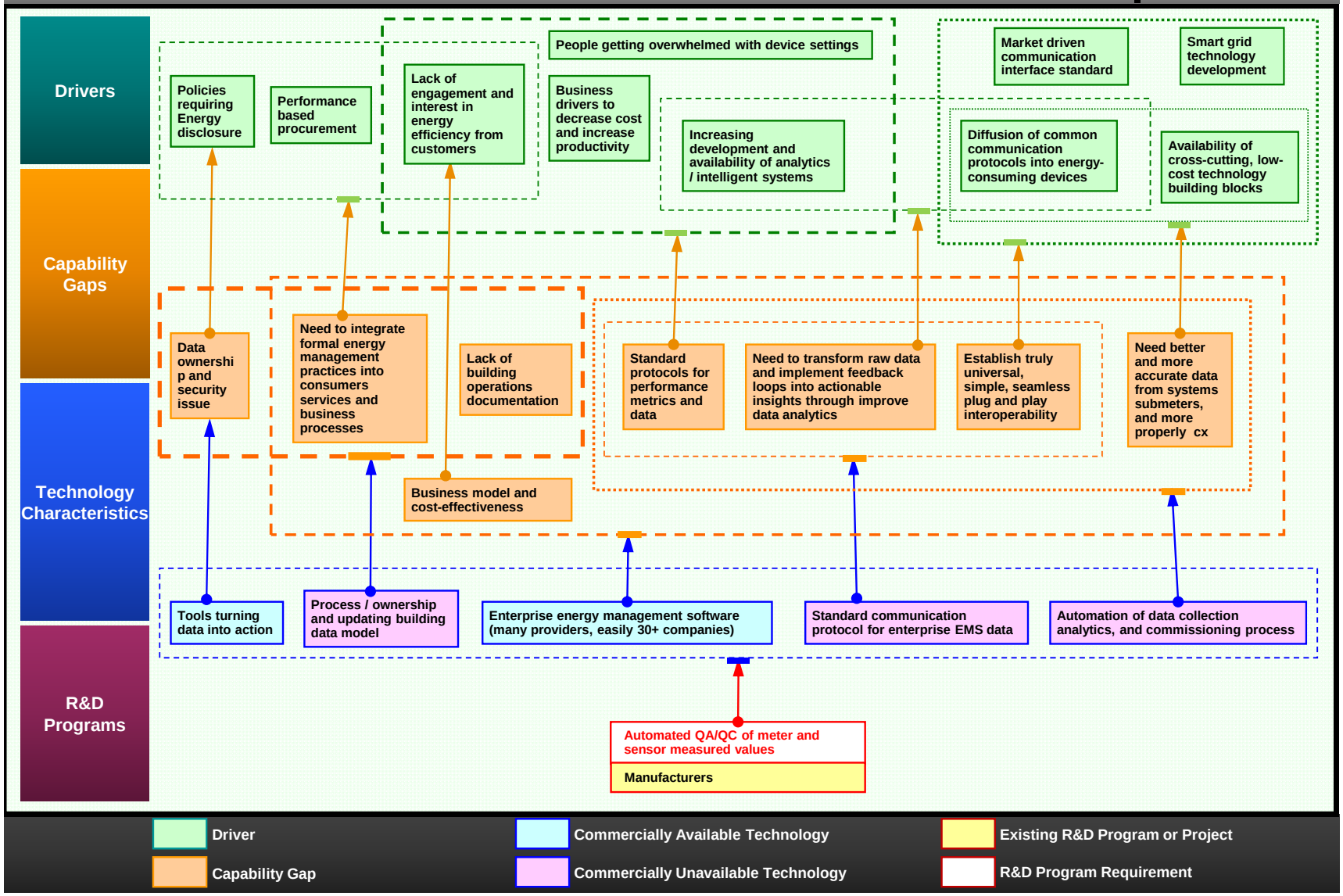
1. How accurate are rapid building assessment techniques (low-touch audits using interval data), and how specifically can these techniques identify building EE and RD opportunities?
2. How accurate are fault detection and diagnostic algorithms (using system-level data) and how actionable are the recommendations?
3. What energy-savings opportunities can automatically be addressed through automated system optimization and which require human analysis and intervention?
4. How can tools with integrated M&V be used to quantify savings at whole building level? What bar for rigor must be met?

Product/Service Area : **SENSORS, METERS, & ENERGY MANAGEMENT SYSTEMS**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Enterprise and Maintenance Management Systems (9 of 9)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Automated QA / QC of meter and sensor measured values. Inaction often results from data provided by enterprise energy and maintenance management systems because the captured data and inaccurate. This data is incorrect because meters and sensors are often installed and configured incorrectly.

Existing research: Manufacturers.

- *[Summaries of existing research pending]*

Key research questions:

1. Are there ways to automate quality assurance (QA) / quality control (QC) of installation and configuration of meters and sensors?
2. Are there ways to semi-automate quality assurance (QA) / quality control (QC) of installations and configuration of meters and sensors?
3. Are there effective guidance documents for implementing quality assurance (QA) / quality control (QC) of meters and sensors

Industrial Food Processing Roadmaps

This section contains the following roadmaps:

- Heating
- Cooling
- Mechanical
- Infrastructure

Other relevant sources:

The list below is intended to be broadly representative rather than exhaustive and will be updated as new information becomes available.

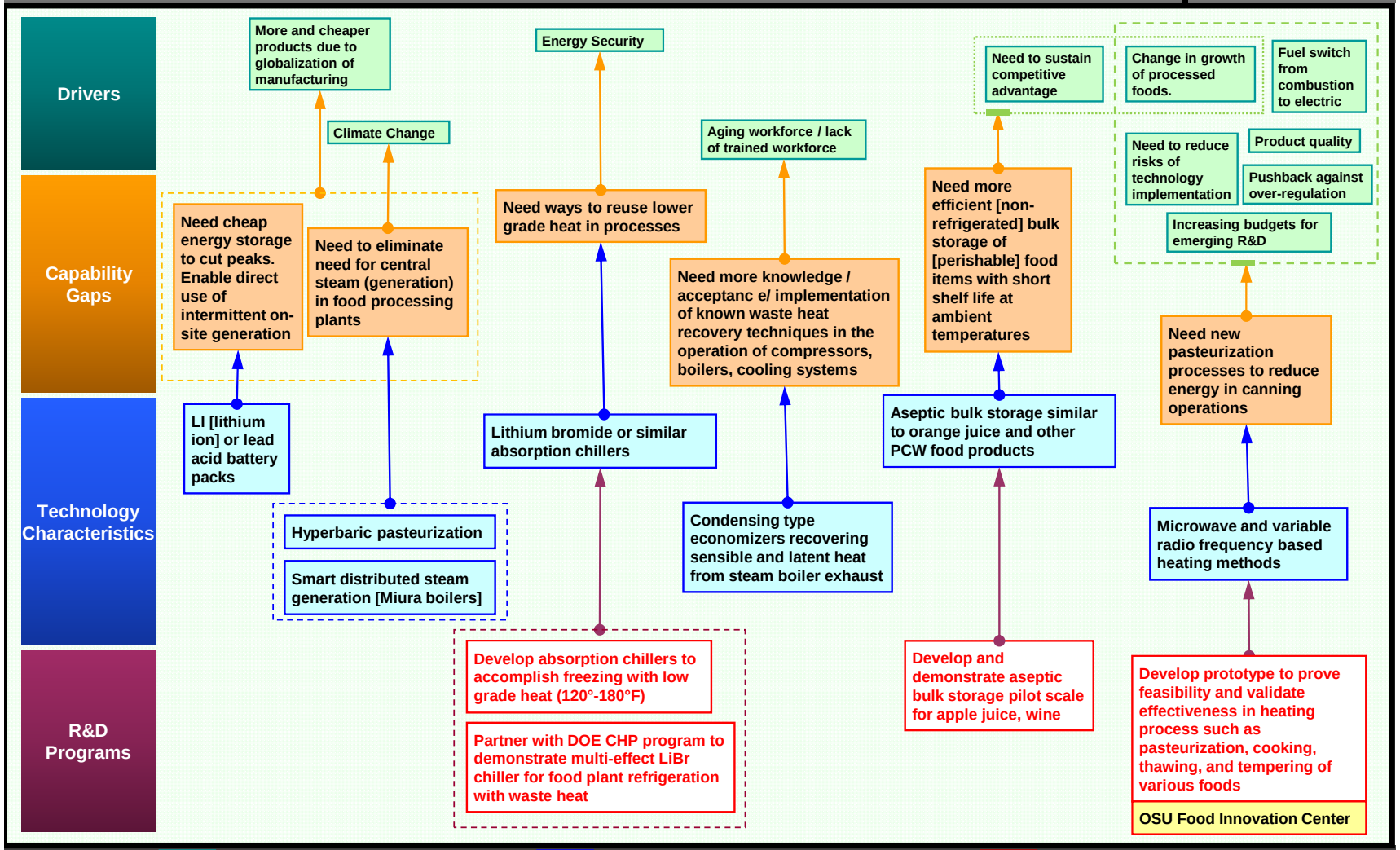
Sources pending.

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Heating (1of 2)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Need to develop prototype to prove feasibility and validate the effectiveness in heating process. Examples include pasteurization, cooking, thawing, tempering of various foods.

Existing research: Ongoing R&D in this area at Oregon State University's Food Innovation Center (http://fic.oregonstate.edu/)..

Key research questions:

1. Questions not yet specified.

Develop absorption chillers to accomplish freezing with low grade heat (120-180F). (Summary not yet provided.).

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Develop and demonstrate aseptic bulk storage pilot scale for apple juice, wine. (Summary not yet provided.).

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Partner with DOE CHP program to demonstrate multi-effect lithium bromide (LiBr) chiller for food plant refrigeration with waste heat. (Summary not yet provided.).

Existing research: None identified.

Key research questions:

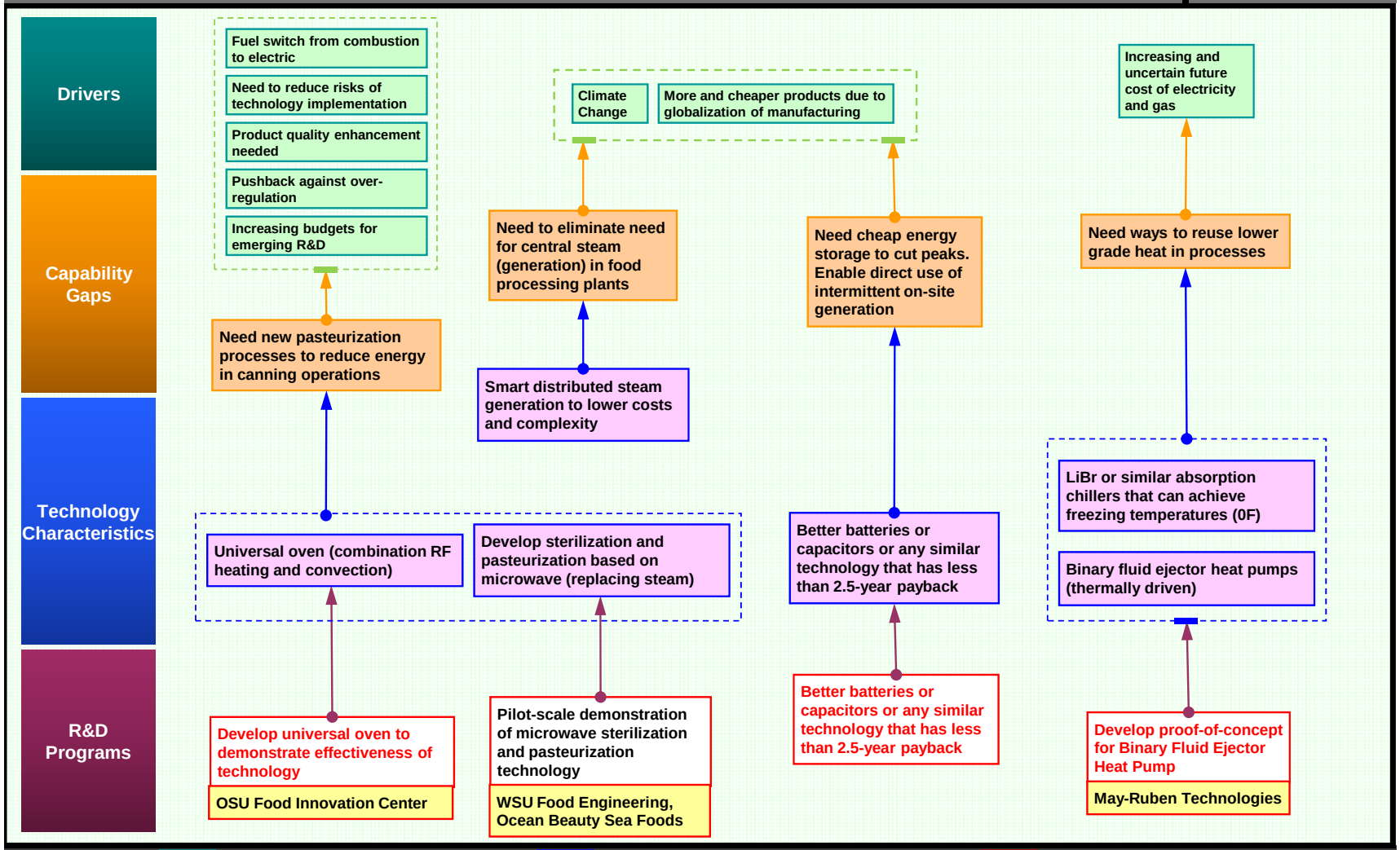
1. Questions not yet specified.

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Heating (2of 2)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Develop proof-of-concept for Binary Fluid Ejector Heat Pump.

(Summary not yet provided.)

Existing research: R&D ongoing at May-Ruben Technologies (http://may-rubentechnologies.com/), contact Research Support Officer Chelsea Ruben, http://may-rubentechnologies.com/index.php?option=com_content&view=article&id=76&Itemid=116.

Key research questions:

1. Questions not yet specified.

Develop universal oven to demonstrate effectiveness of technology. (Summary not yet provided.)

Existing research: Ongoing R&D in this area at Oregon State University's Food Innovation Center (http://fic.oregonstate.edu/).

Key research questions:

1. Questions not yet specified.

Pilot-scale demonstration of microwave sterilization and pasteurization technology. (Summary not yet provided.)

Existing research: Ongoing R&D in this area involving the Food Engineering team of Washington State University's (WSU) Biological Systems Engineering department (http://bsyse.wsu.edu/core/research/Emphasis/Food/Food.html), and at Ocean Beauty Sea Foods, LLC (http://www.oceanbeauty.com/).

Key research questions:

1. Questions not yet specified.

Better batteries or capacitors or any similar technology that has less than 2.5-year payback. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

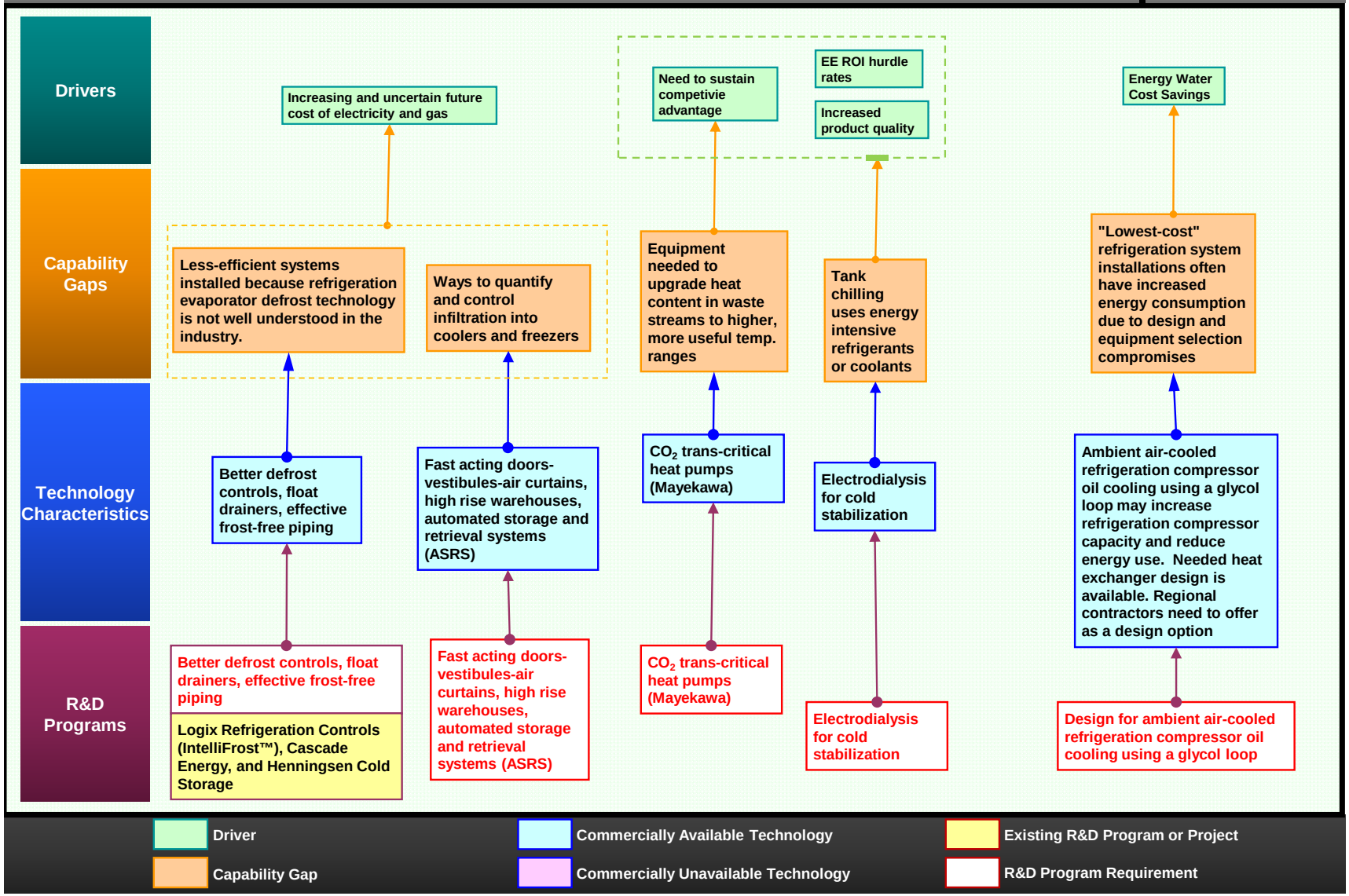
1. Questions not yet specified.

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Cooling (1 of 4)**

See "Technology Area Definitions" section



R&D Program Summaries

Better defrost controls, float drainers, effective frost-free piping. (Summary not yet provided.)

Existing research: Stakeholders referred to R&D that includes Logix Refrigeration Controls' IntelliFrost™ product and work at Cascade Energy and Henningsen Cold Storage.

- Logix® IntelliFrost™ Automatic Defrost System: http://www.logix-controls.com/docs/Logix_IntelliFrost_ Technical_Brief.pdf.
- Cascade Energy: http://www.cascadeenergy.com/default.asp.
- Henningsen Cold Storage: henningsen.com

Key research questions:

1. Questions not yet specified.

Fast acting doors-vestibules-air curtains, high rise warehouses, automated storage and retrieval systems (ASRS). (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

CO_2 trans-critical heat pumps. See Mayekawa, http://www.mayekawausa.com.

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Electrodialysis for cold stabilization. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Design for ambient air-cooled refrigeration compressor oil cooling using a glycol loop. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

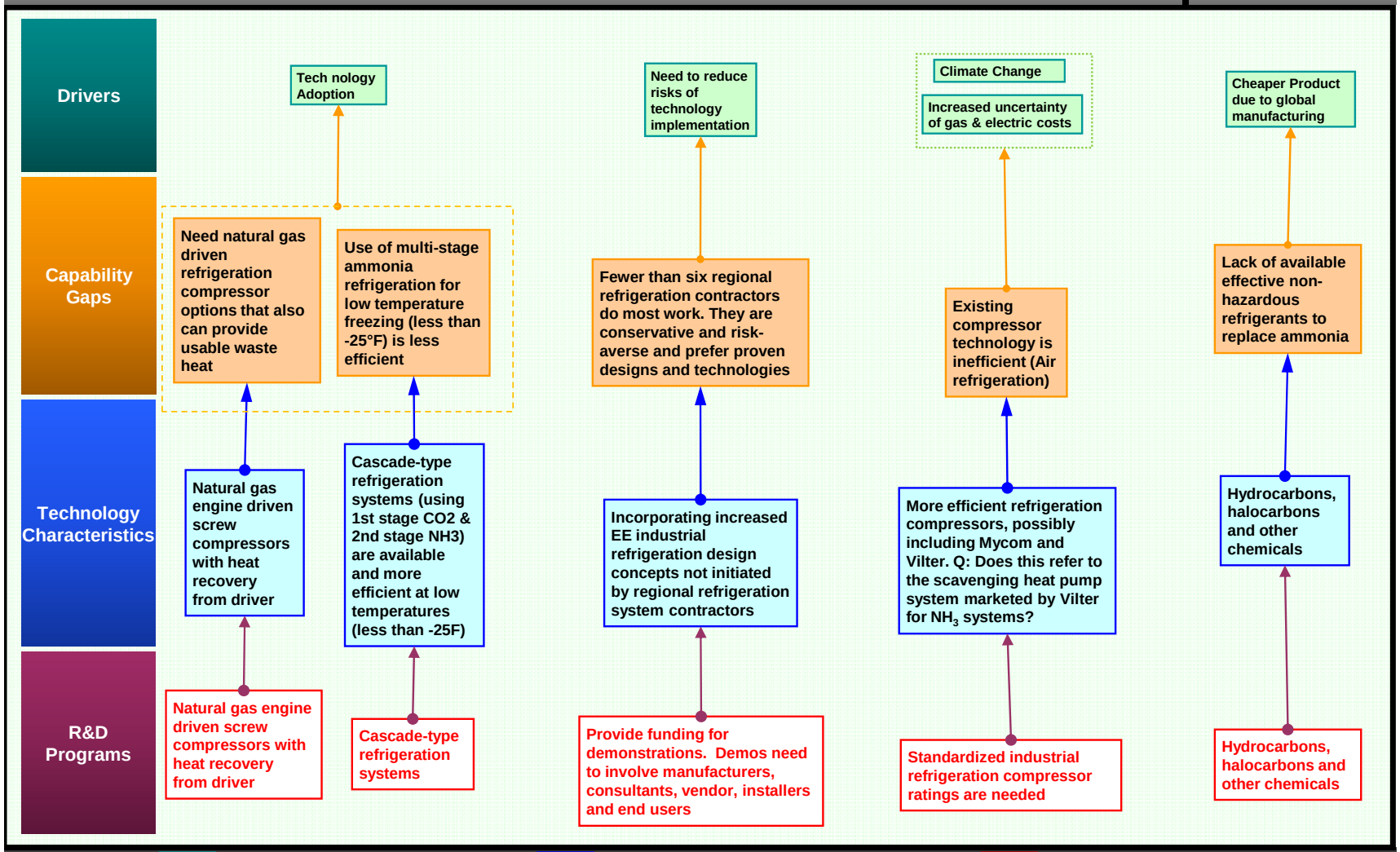
1. Questions not yet specified.

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Cooling (2 of 4)**

See "Technology Area Definitions" section



R&D Program Summaries

Standardized industrial refrigeration compressor ratings are needed. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Provide funding for demonstrations. Demos need to involve manufacturers, consultants, vendor, installers and end users.

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Natural gas engine driven screw compressors with heat recovery from driver. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Cascade-type refrigeration systems. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Hydrocarbons, halocarbons and other chemicals. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

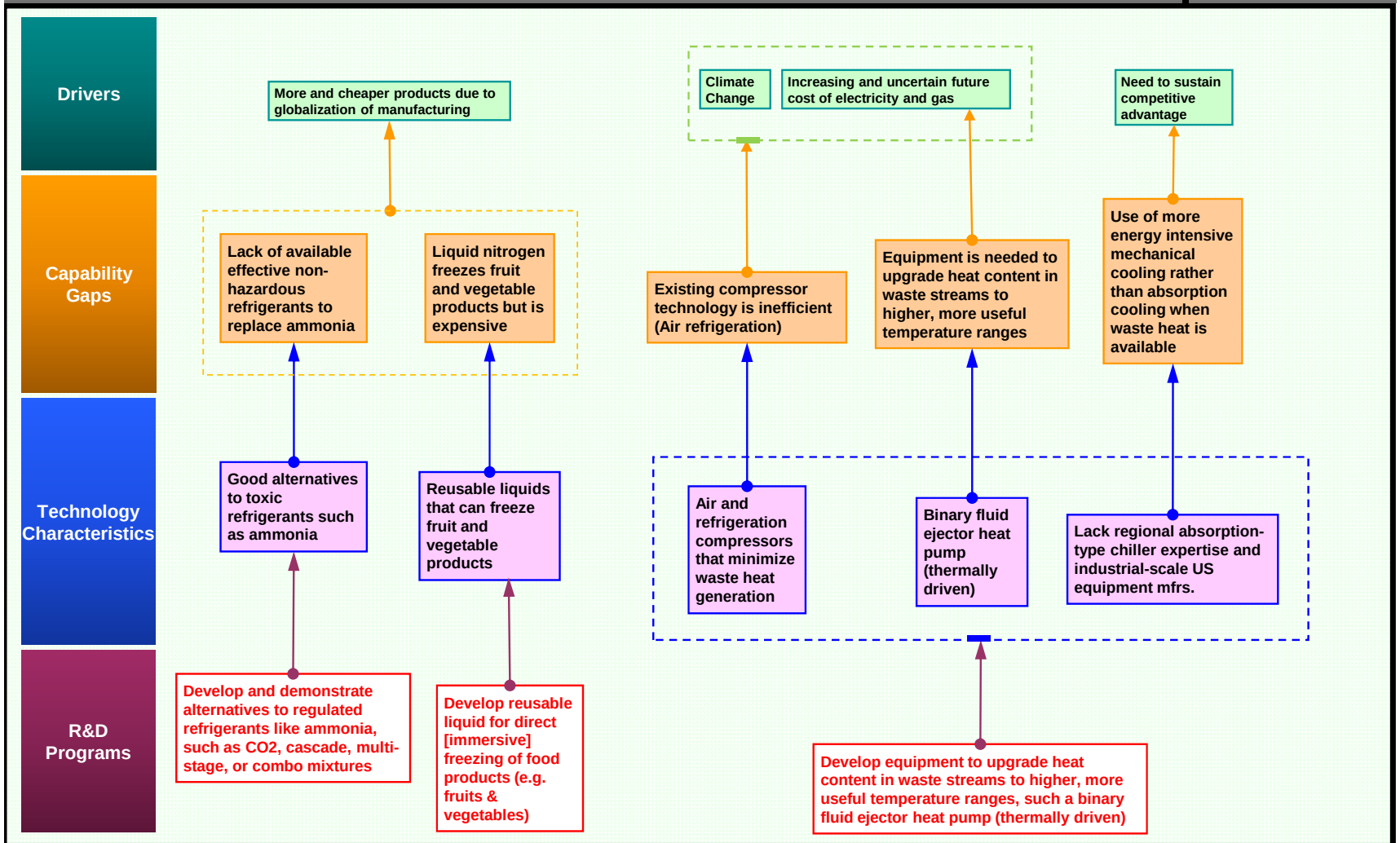
1. Questions not yet specified.

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Cooling (3 of 4)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Develop reusable liquid for direct [immersive] freezing of food products (e.g. fruits & vegetables). (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Develop equipment to upgrade heat content in waste streams to higher, more useful temperature ranges, such a binary fluid ejector heat pump (thermally driven). (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Develop and demonstrate alternatives to regulated refrigerants like ammonia, such as CO2, cascade, multi-stage, or combo mixtures. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

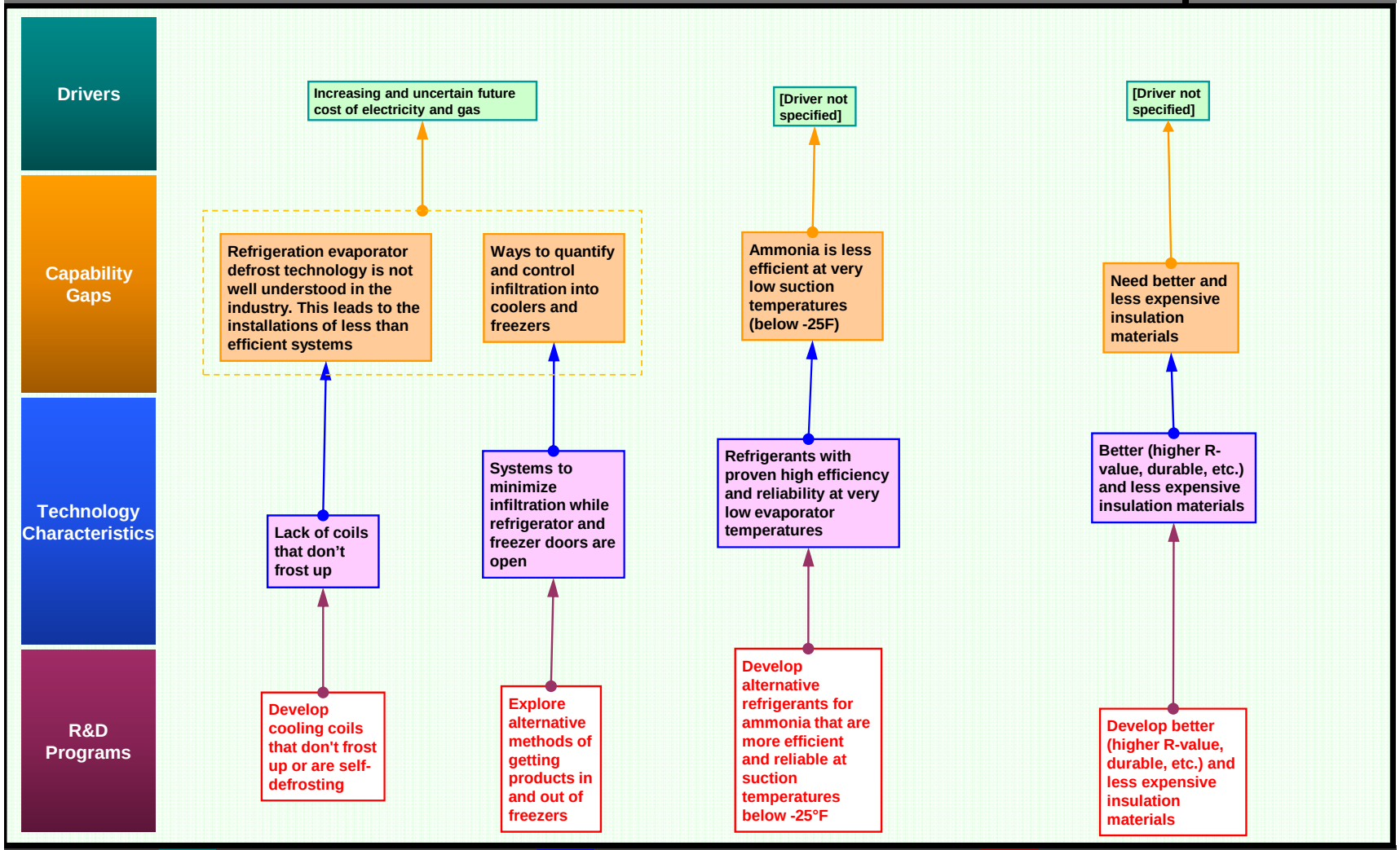
1. Questions not yet specified.

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Cooling (4 of 4)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Explore alternative methods of getting products in and out of freezers. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Develop cooling coils that don't frost up or are self-defrosting.
Summary.

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Develop better (higher R-value, durable, etc.) and less expensive insulation materials. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Develop alternative refrigerants for ammonia that are more efficient and reliable at suction temperatures below -25°F.
(Summary not yet provided.)

Existing research: None identified.

Key research questions:

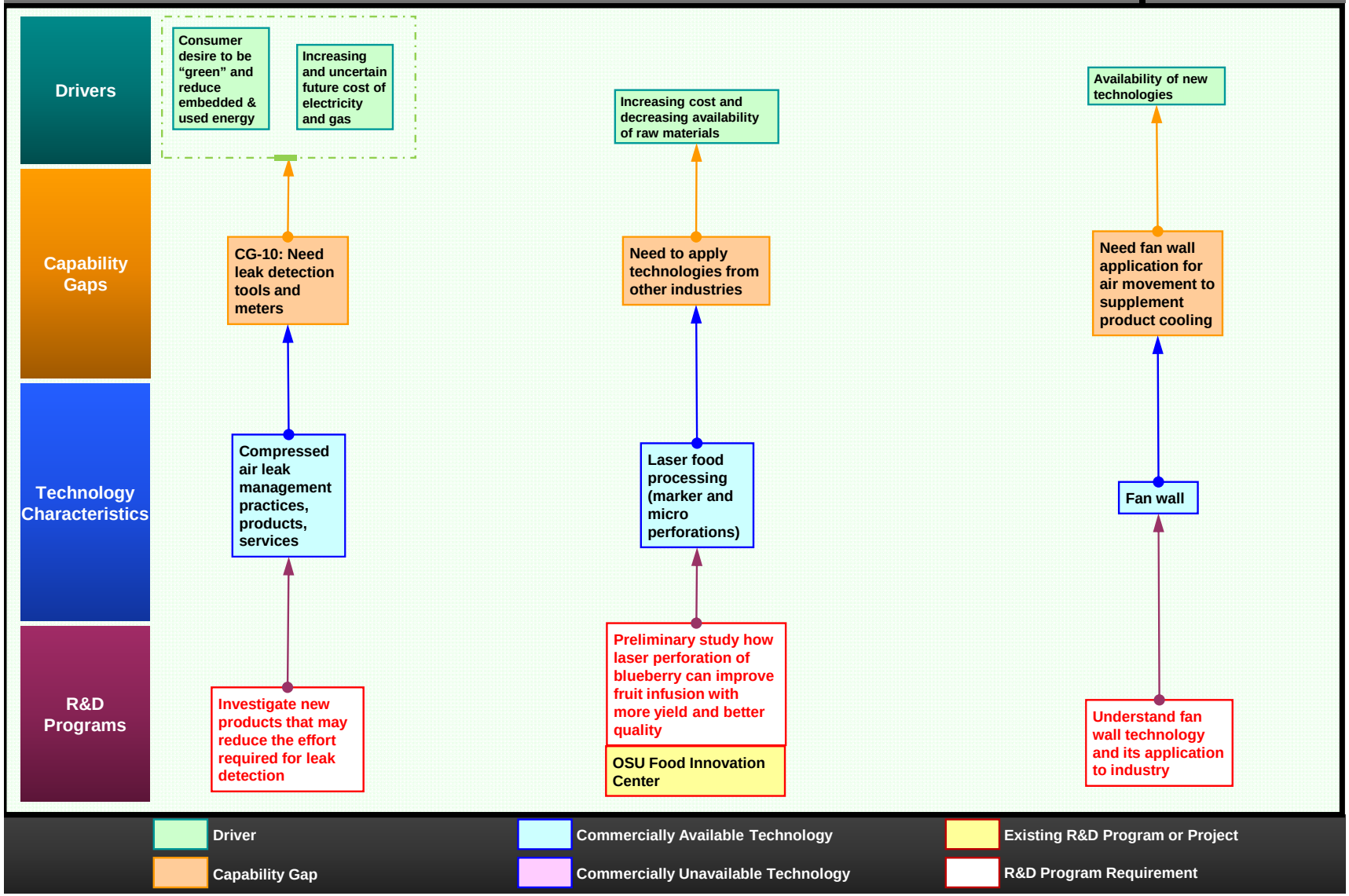
1. Questions not yet specified.

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Mechanical (1 of 4)**

See "Technology Area Definitions" section



R&D Program Summaries

Preliminary study how laser perforation of blueberry can improve fruit infusion with more yield and better quality. (Summary not yet provided.)

Existing research: Ongoing R&D in this area at Oregon State University's Food Innovation Center (http://fic.oregonstate.edu/).

Key research questions:

1. Questions not yet specified.

Investigate new products that may reduce the effort required for leak detection. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified.

Understand the fan wall technology and its application to industry. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

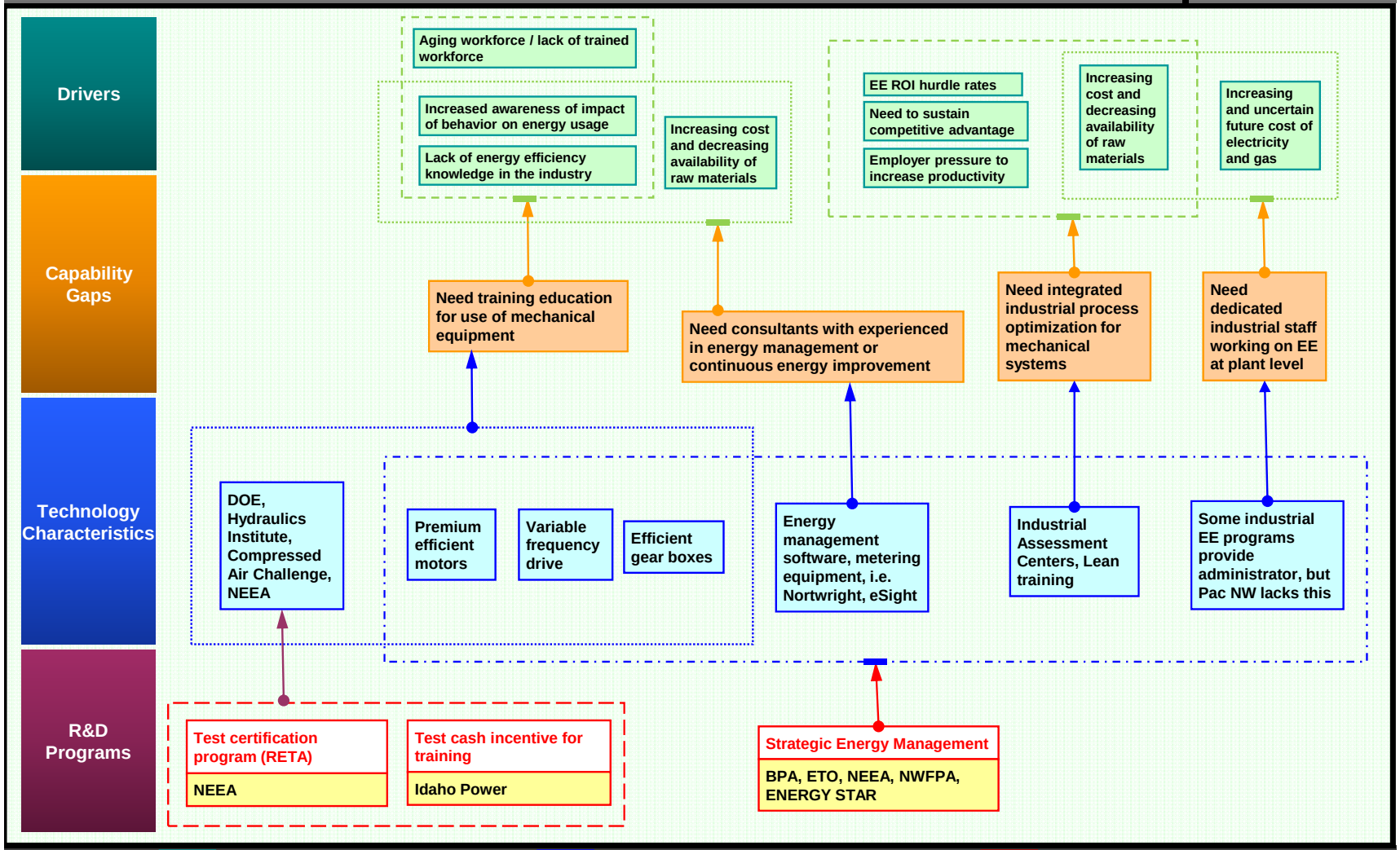
1. Questions not yet specified.

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Mechanical (2 of 4)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Strategic Energy Management. (Summary not yet provided.)

Existing research: The Northwest Energy Efficiency Alliance (NEEA), the ENERGY STAR program, Bonneville Power Administration (BPA), and the Northwest Food Processors Association (NWFPA) are involved in developing Strategic Energy Management solutions.

- NEEA's work in this area includes a Strategic Energy Management study they released in January 2012; see http://neea.org/research/reportdetail.aspx?ID=1619.
- ENERGY STAR Strategic Energy Management approach: http://www.energystar.gov/index.cfm?c=guidelines.guidelines_index.
- BPA Energy Efficiency staff are working in this area ().
- NWFPA's work in this area can be found at http://www.nwfpa.org/nwfpa.info/component/content/article/37-boiler/55--energy-roadmap-projects-put-nwfpa-membership-on-the-road

Key research questions:

1. Questions not yet specified.

Test cash incentive for training. (Summary not yet provided.)

Existing research: Stakeholders indicated that the Northwest Energy Efficiency Alliance (NEEA) is working in this area; see http://neea.org/.

Key research questions:

1. Questions not yet specified.

Test certification program. (Summary not yet provided.)

Existing research: See programs at RETA and NEEA.

- Refrigerating Engineers & Technicians Association (RETA), http://www.reta.com/.
- Northwest Energy Efficiency Alliance (NEEA); http://neea.org/.

Key research questions:

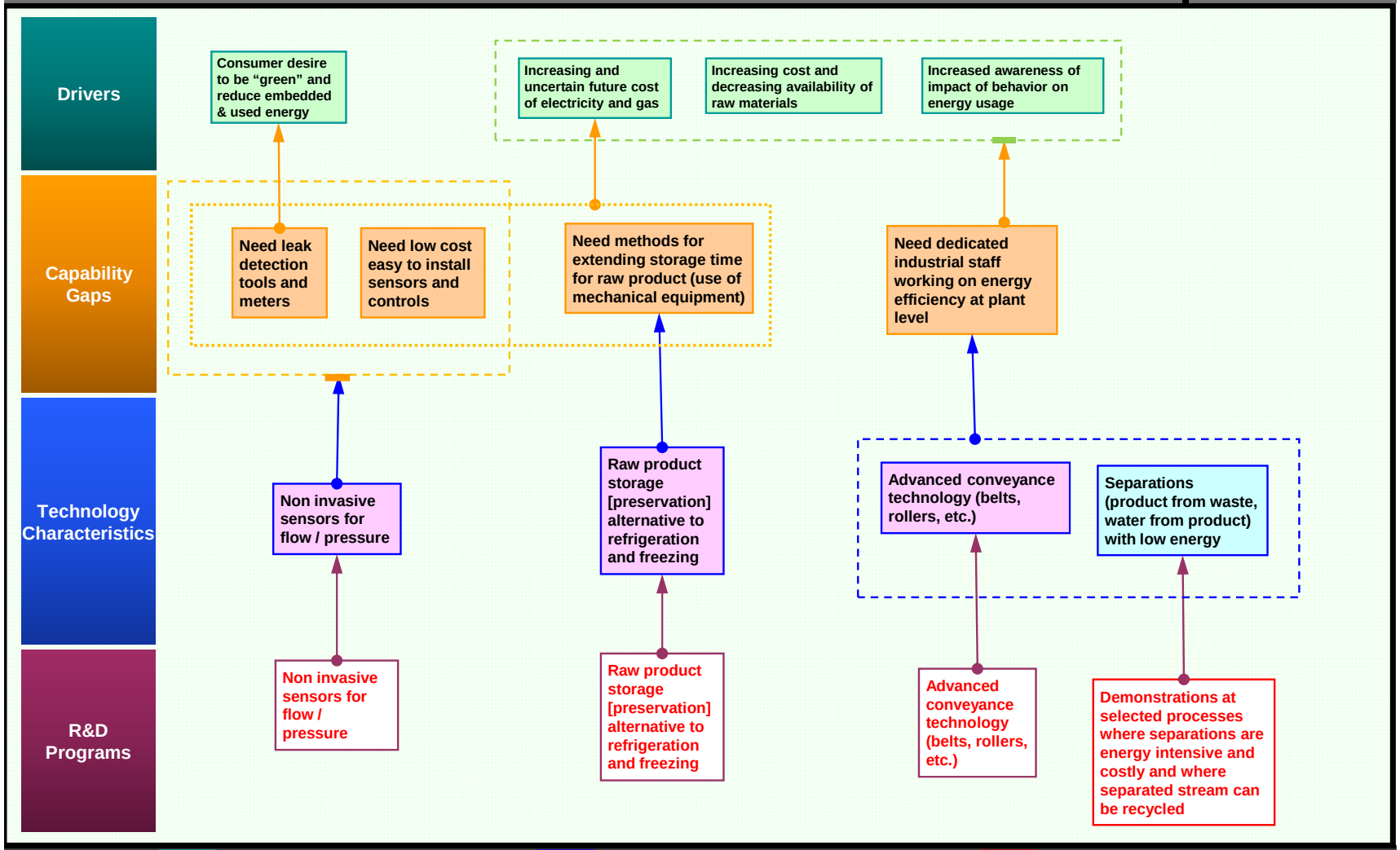
1. Questions not yet specified.

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Mechanical (3 of 4)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Advanced conveyance technology (belts, rollers, etc.). (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Demonstrations at selected processes where separations are energy intensive and costly and where separated stream can be recycled. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Non invasive sensors for flow / pressure. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Raw product storage [preservation] alternative to refrigeration and freezing. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

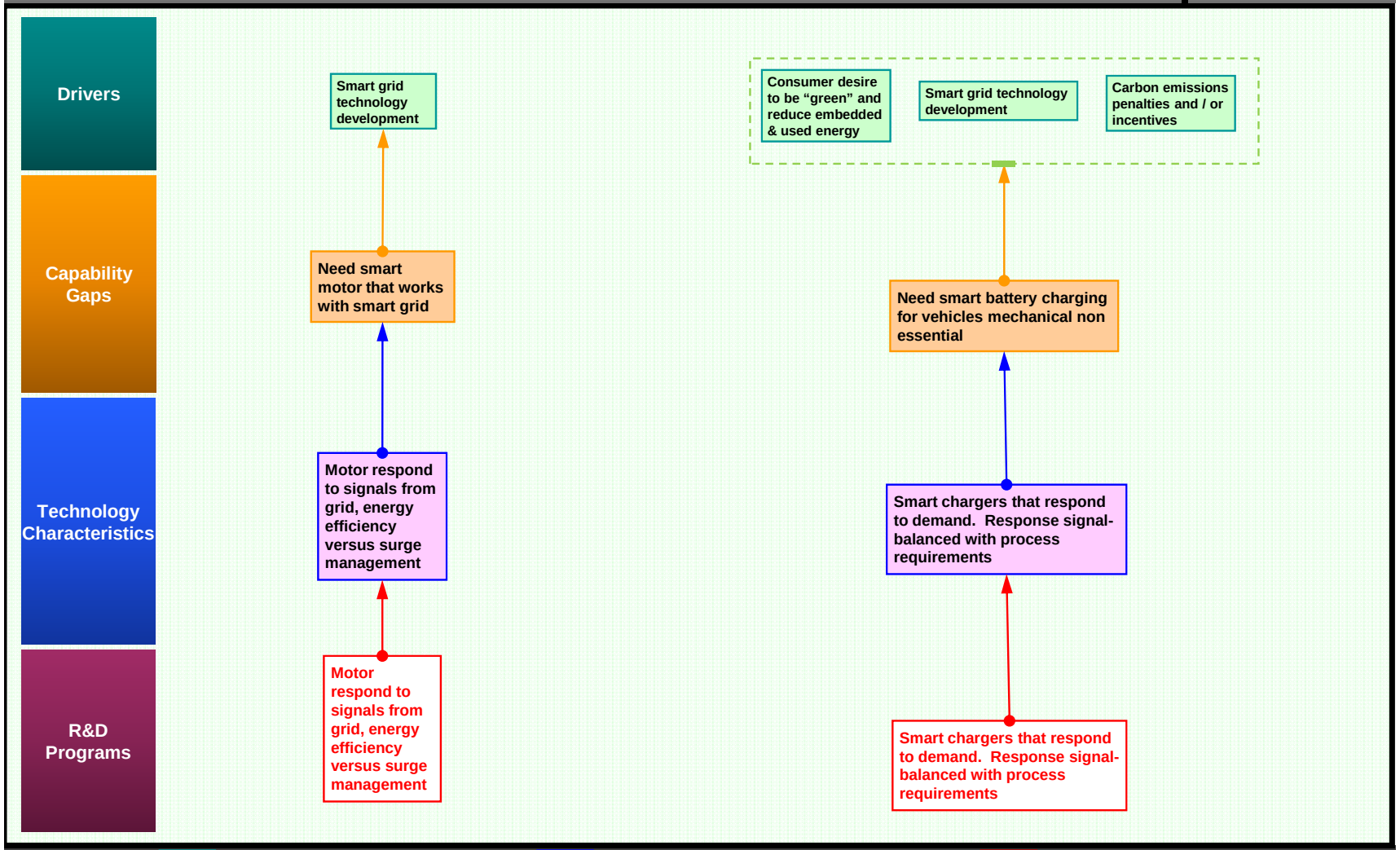
1. Questions not yet specified

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Mechanical (4 of 4)**

See "Technology Area Definitions" section



Driver | Commercially Available Technology | Existing R&D Program or Project

Capability Gap | Commercially Unavailable Technology | R&D Program Requirement

R&D Program Summaries

Motor respond to signals from grid, energy efficiency versus surge management. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Smart chargers that respond to demand. Response signal-balanced with process requirements. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

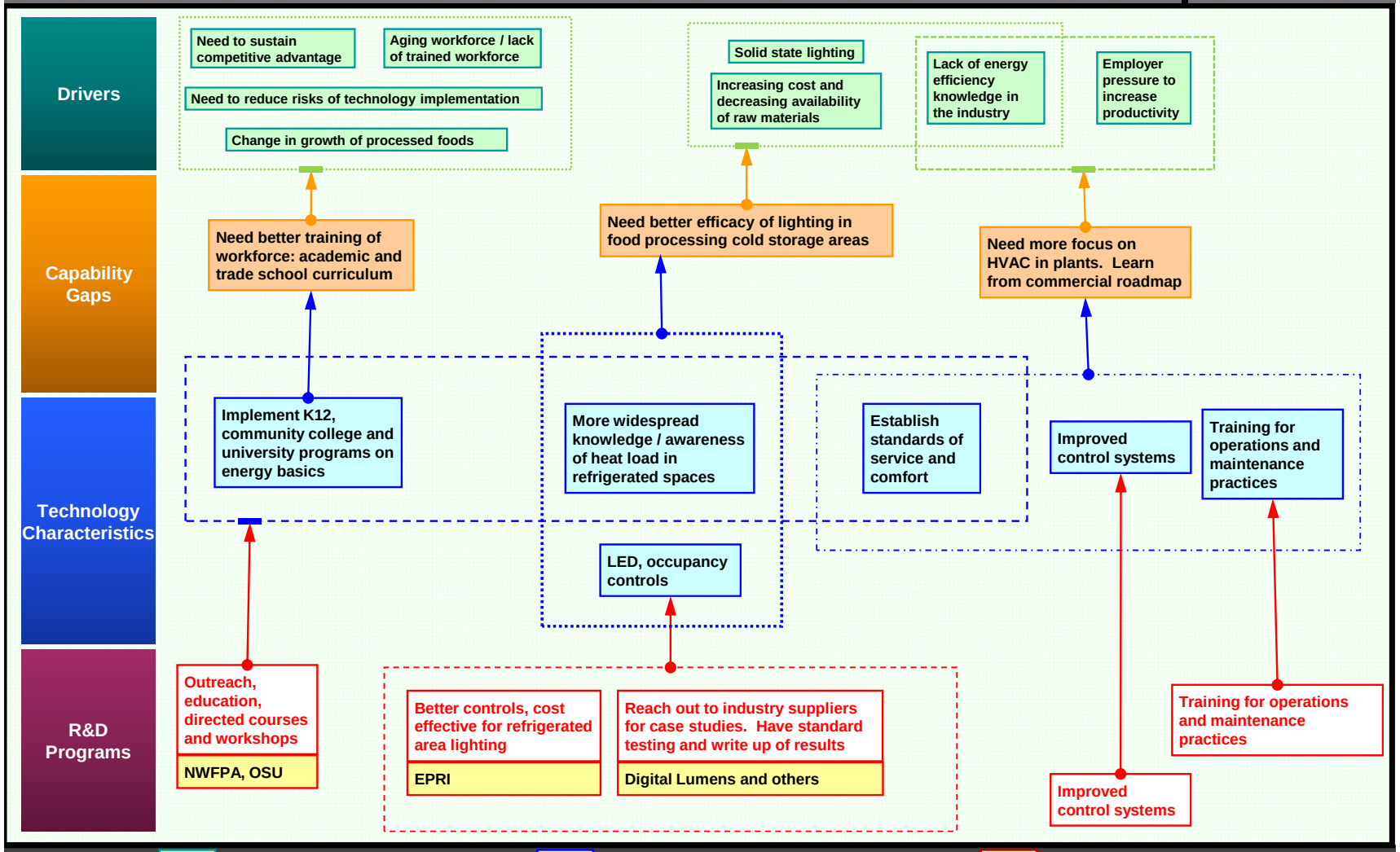
1. Questions not yet specified

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Infrastructure (1 of 6)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Better controls, cost effective for refrigerated area lighting. (Summary not yet provided.)

Existing research: Ongoing R&D at the Electric Power Research Institute (EPRI, http://et.epri.com/index.html).

Key research questions:

1. Questions not yet specified

Outreach, education, directed courses and workshops. (Summary not yet provided.)

Existing research: Ongoing R&D at the Northwest Food Processors Association (NWFPA, http://www.nwfpa.org/) and in Oregon State University's (OSU) Department of Food Science and Technology (http://oregonstate.edu/dept/foodsci/extservices/ext_index.htm).

Key research questions:

1. Questions not yet specified

Reach-out to industry suppliers for case studies. Have standard testing and write up of results

Existing research: Stakeholders indicated ongoing R&D at Digital Lumens (www.digitallumens.com) and others.

Key research questions:

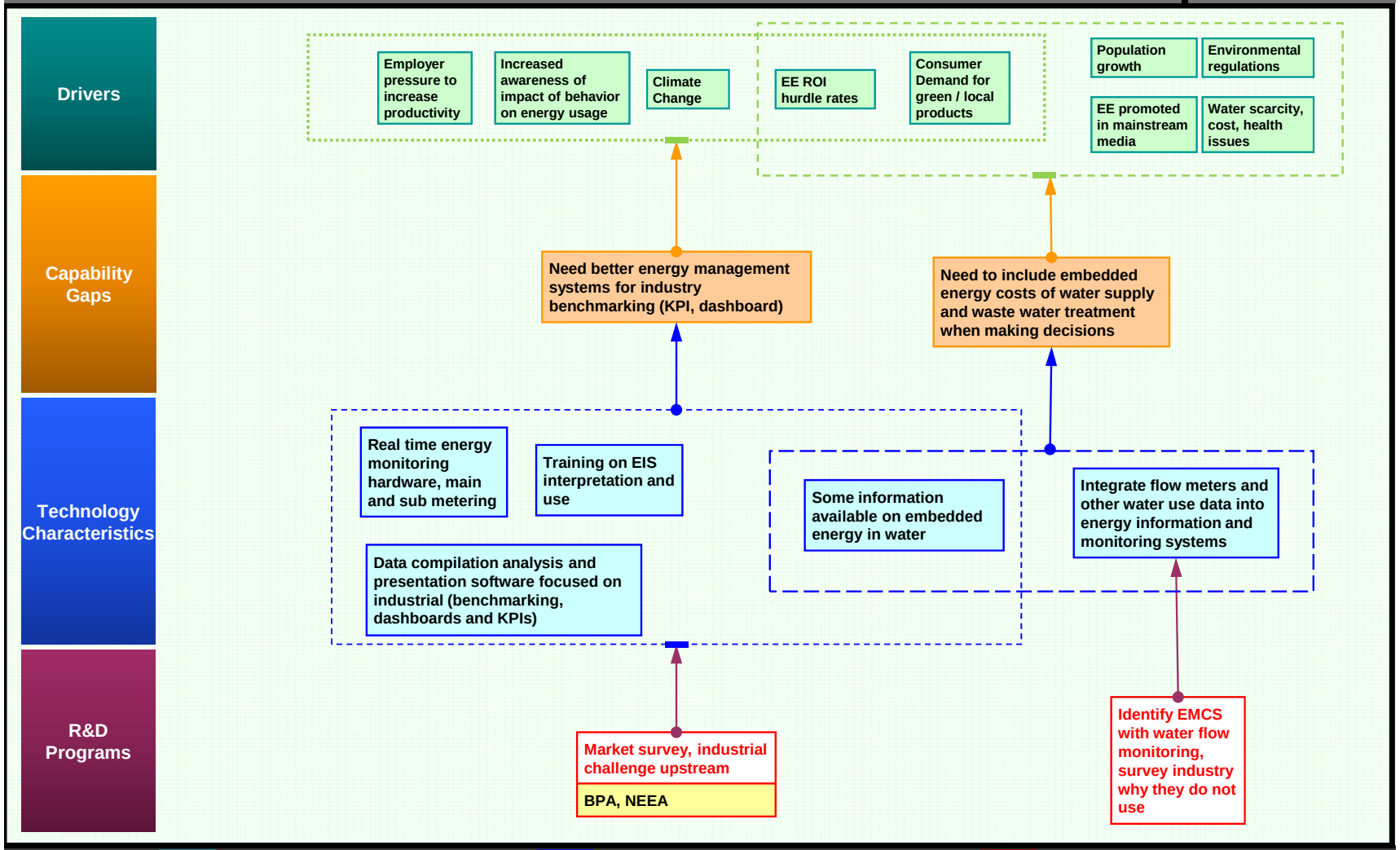
1. Questions not yet specified

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Infrastructure (2 of 6)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Market survey, industrial challenge upstream. (Summary not yet provided.)

Existing research: Ongoing R&D at the Bonneville Power Administration's (BPA) Energy Efficiency department (http://www.bpa.gov/Energy/N/) and the Northwest Energy Efficiency Alliance (NEEA, http://neea.org/).

Key research questions:

1. Questions not yet specified

Identify EMCS with water flow monitoring, survey industry why they do not use. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

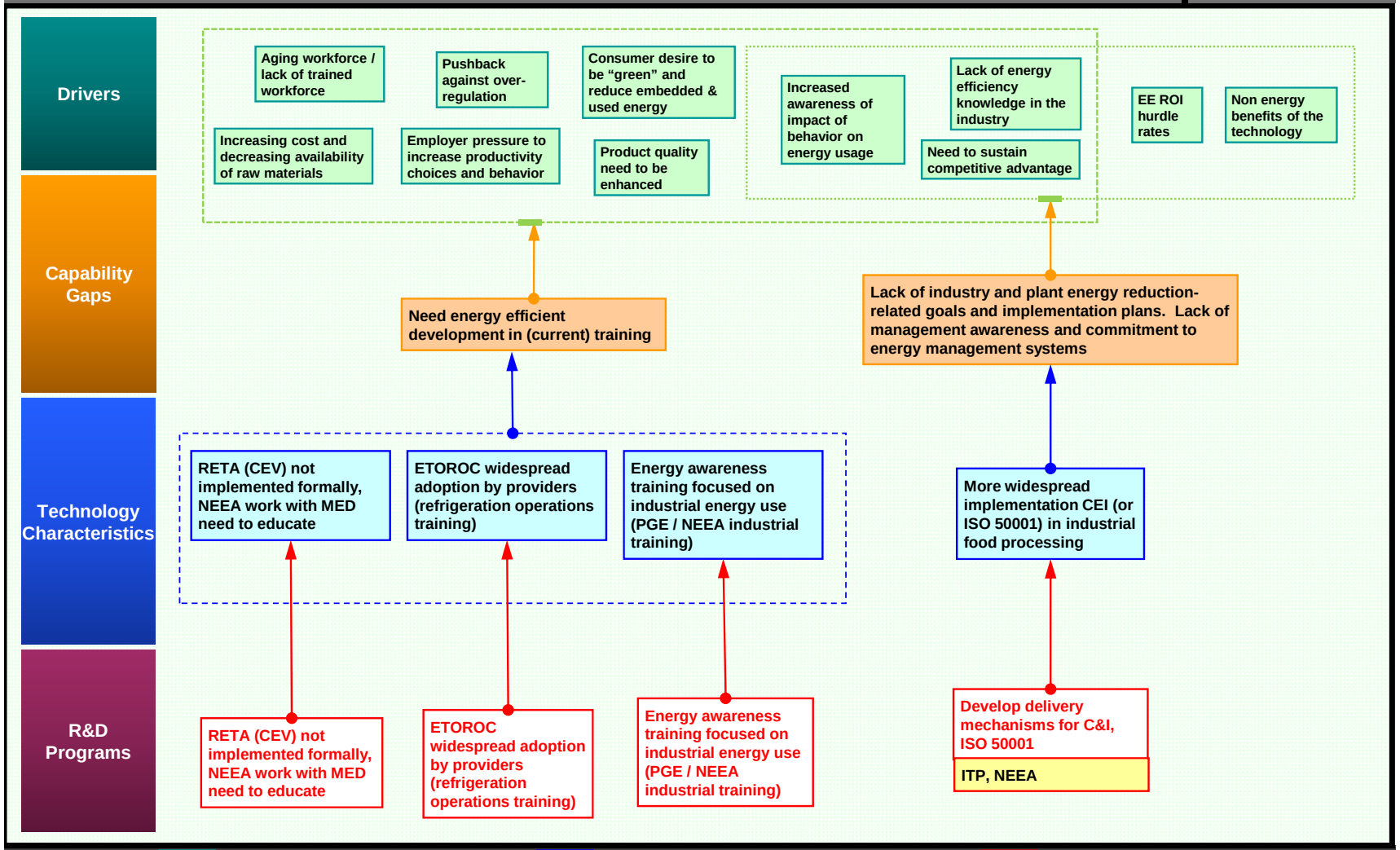
1. Questions not yet specified

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Infrastructure (3 of 6)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Develop delivery mechanisms for C&I, ISO 50001. (Summary not yet provided.)

Existing research: Research in this area is ongoing at the U.S. Department of Energy's (DOE) Advanced Manufacturing Office (AMO, formerly known as the Industrial Technologies Program or ITP; see http://www1.eere.energy.gov/ manufacturing/) and Northwest Energy Efficiency Alliance (NEEA, http://neea.org/).

Key research questions:

1. Questions not yet specified

RETA (CEV) not implemented formally, NEEA work with MED need to educate. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

ETOROC widespread adoption by providers (refrigeration operations training). (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Energy awareness training focused on industrial energy use (PGE / NEEA industrial training). (Summary not yet provided.)

Existing research: None identified.

Key research questions:

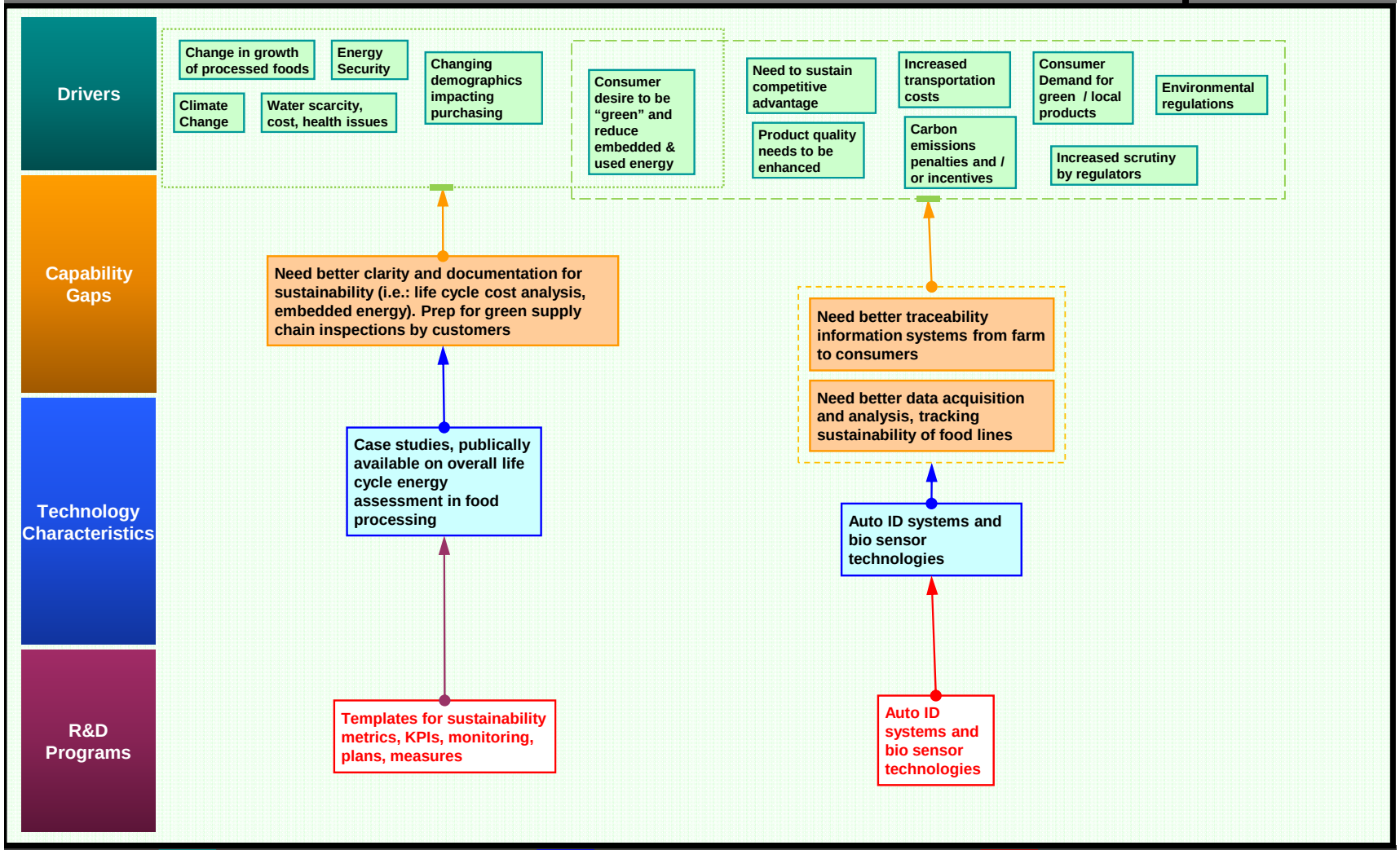
1. Questions not yet specified

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Infrastructure (4 of 6)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Templates for sustainability metrics, KPIs, monitoring, plans, measures. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Auto ID systems and bio sensor technologies. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

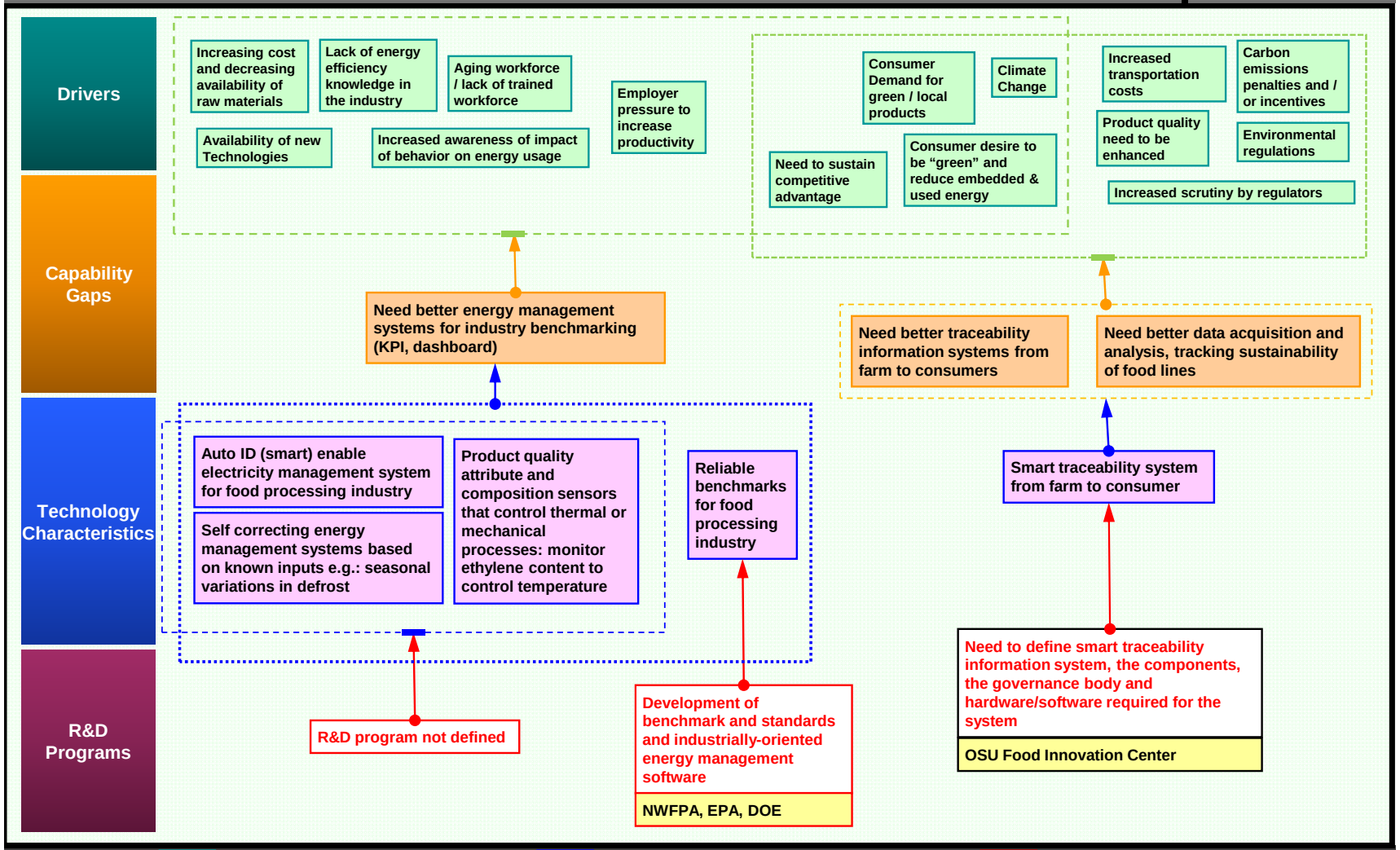
1. Questions not yet specified

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Infrastructure (5 of 6)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Development of benchmark and standards and industrially-oriented energy management software. (Summary not yet provided.)

Existing research: Research ongoing at the Northwest Food Processors Association (NWFPA, http://www.nwfpa.org/) and at the U.S. Environmental Protection Agency (EPA) and the U.S. Department of Energy (DOE) [is this EPA-DOE collaboration the ENERGY STAR program? See http://www.energystar.gov/ index.cfm?c=home.index).

Key research questions:

1. Questions not yet specified

Need to define smart traceability information system, the components, the governance body and hardware/software required for the system. (Summary not yet provided.)

Existing research: Research is ongoing at the Oregon State University (OSU) Food Innovation Center (http://fic.oregonstate.edu/).

Key research questions:

1. Questions not yet specified

R&D program not defined. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

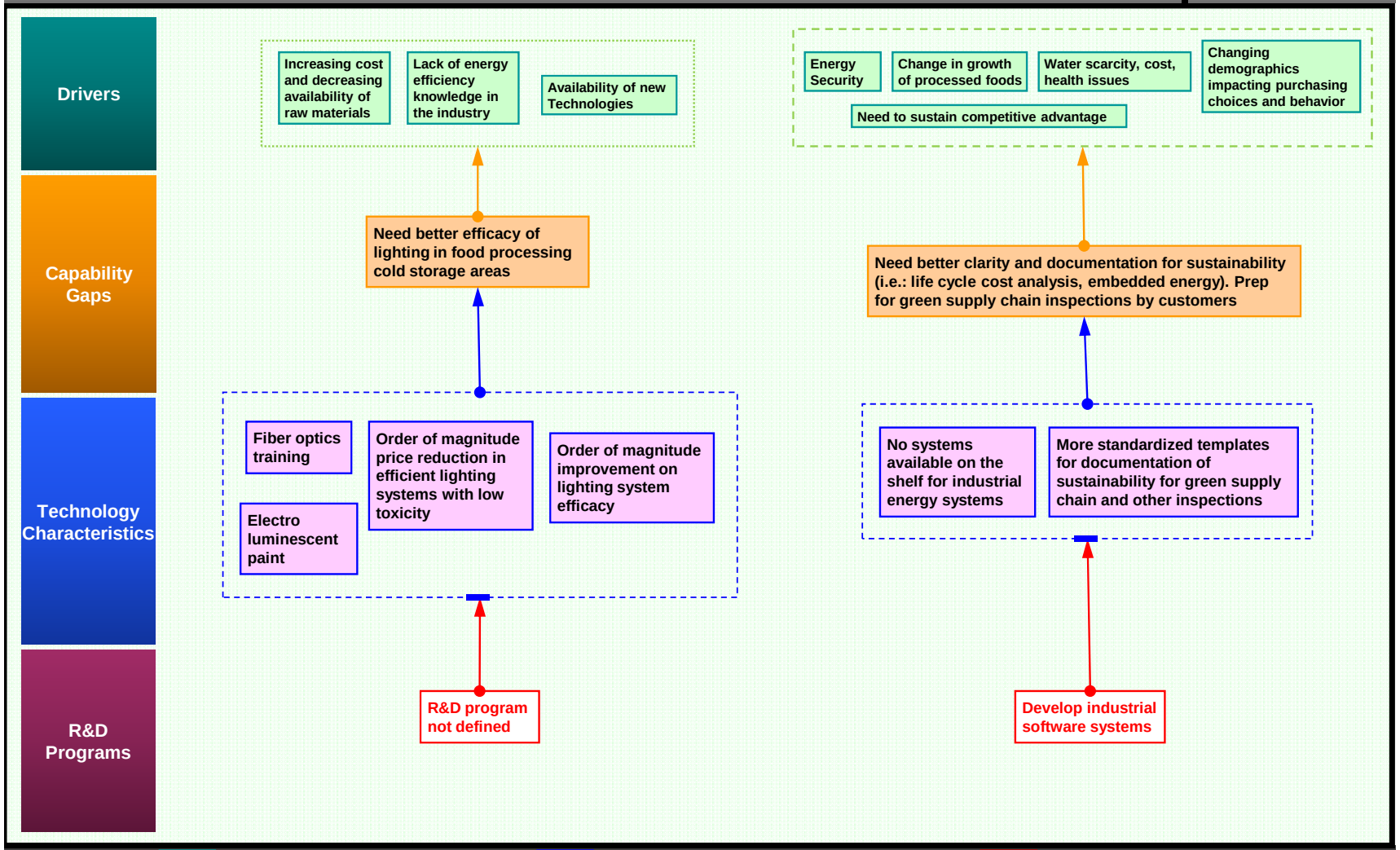
1. Questions not yet specified

Product/Service Area : **INDUSTRIAL FOOD PROCESSING**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Infrastructure (6 of 6)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Develop industrial software systems. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

R&D program not defined. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Combined Heat and Power (CHP) Roadmaps

This section contains the following roadmaps:

- Production
- Resources
- Delivery

Selected Sources Regarding Combined Heat and Power Research and Development in the United States

BCS, Incorporated, Waste Heat Recovery: Technology and Opportunities in U.S. Industry. Washington, D.C.: U.S. Department of Energy Industrial Technologies Program, March 2008.

Energy and Environmental Analysis, Inc., "Combined Heat and Power Installation Database," [last updated May 10, 2010], http://www.eea-inc.com/chpdata/, accessed March 2, 2012.

Heat is Power, http://www.heatispower.org/.

Anna Shipley, Anne Hampson, Bruce Hedman, Patti Garland, and Paul Bautista. Combined Heat and Power: Effective Energy Solutions for a Sustainable Future. ORNL/TM-2008/224. Oak Ridge, Tenn.: Oak Ridge National Laboratory, Dec. 2008.

William Steigelmann and Barry Hinkle, "CHP: The 'Ugly Duckling' of Energy Efficiency," Report 1335, International Energy Program Evaluation Conference, 2009, http://www.cee1.org/eval/db_pdf_es/1335es.pdf.

U.S. Clean Heat and Power Association, http://www.uschpa.org/i4a/pages/index.cfm?pageid=1.

U.S. Clean Heat and Power Association, "National CHP Roadmap: Doubling Combined Heat and Power Capacity in the United States by 2010," March 2001, http://www1.eere.energy.gov/manufacturing/distributedenergy/pdfs/chp_national_roadmap.pdf, accessed March 2, 2012.

U.S. Environmental Protection Agency. "Combined Heat and Power Partnership." http://www.epa.gov/chp/.

U.S. Department of Energy Northwest Clean Energy Application Center. http://www.chpcenternw.org/.

Combined Heat and Power and Waste Heat Recovery Policy Landscape in the Pacific Northwest

To develop a more nuanced idea of what barrier(s) exist for CHP and waste heat recovery development in the Pacific Northwest, in late 2011 Bonneville Power Administration staff began developing a "Combined Heat and Power / Waste Heat Recovery Policy Landscape Report." External stakeholders will provide critical commentary to the draft report prior to its completion, tentatively scheduled for early 2013.

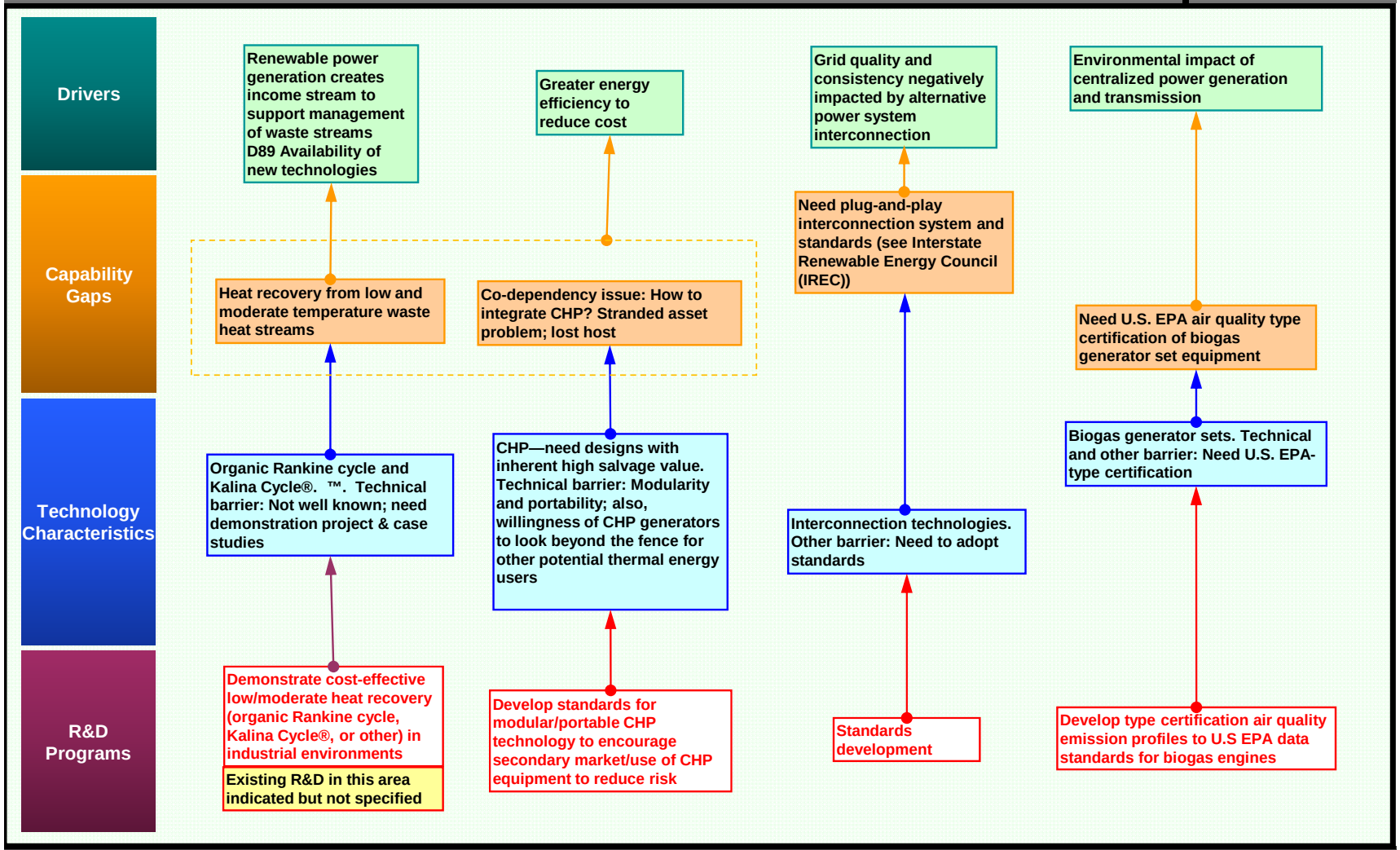
Once completed, the Policy Landscape Report will be paired with the CHP Energy Efficiency Technology Roadmap to provide regional stakeholders with a much more complete understanding of the technology and policy barriers associated with any future investments in combined heat and power and waste heat recovery systems.

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Production (1 of 7)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Demonstrate cost-effective low/moderate heat recovery (organic Rankine cycle, Kalina Cycle®, or other) in industrial environments. (Summary not yet provided.)

Existing research: As of March 2012 roadmapping workshop participants indicated that there was ongoing R&D in this but did not specify where the R&D was being done.

Key research questions:

1. Questions not yet specified

Develop standards for modular/portable CHP technology to encourage secondary market/use of CHP equipment to reduce risk. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Standards development. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop type certification air quality emission profiles to U.S EPA data standards for biogas engines. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

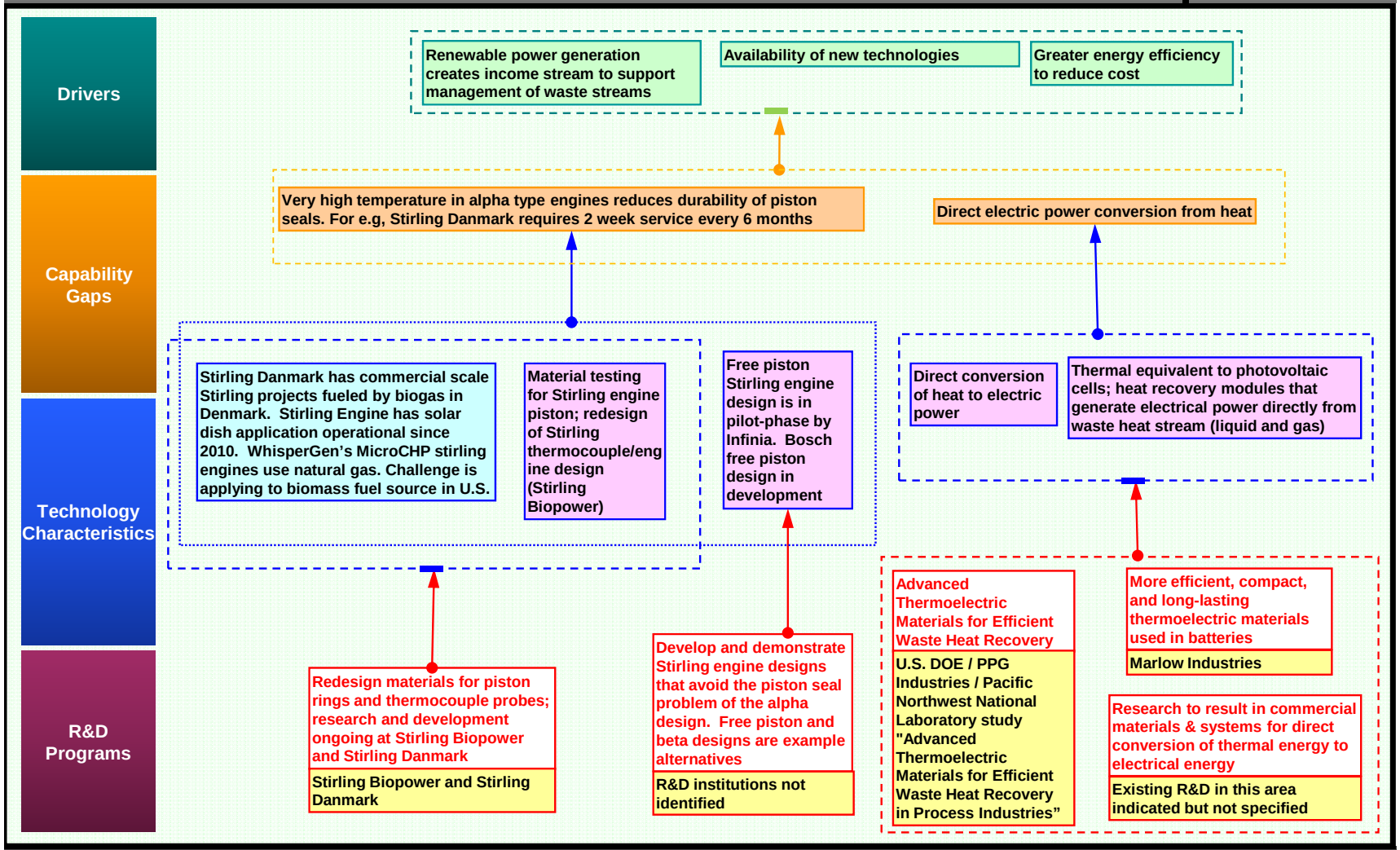
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Production (2 of 7)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Advanced Thermoelectric Materials for Efficient Waste Heat Recovery. (Summary not yet provided.)

Existing research: See U.S. DOE / PPG Industries / Pacific Northwest National Laboratory study, "Advanced Thermoelectric Materials for Efficient Waste Heat Recovery in Process Industries" (http://www1.eere.energy.gov/industry/imf/pdfs/14cps_16947_advanced_thermoelectric_materials.pdf).

Key research questions:

1. Questions not yet specified

Develop and demonstrate Stirling engine designs that avoid the piston seal problem of the alpha design. Free piston and beta designs are example alternatives

Existing research: Workshop participants indicated ongoing research in this area but specific institutions not identified.

Key research questions:

1. Questions not yet specified

More efficient, compact, and long-lasting thermoelectric materials used in batteries. (Summary not yet provided.)

Existing research: R&D ongoing at Marlow Industries (http://www.marlow.com/resources/future-concepts/power-generators-page2.html)..

Key research questions:

1. Questions not yet specified

Redesign materials for piston rings and thermocouple probes. (Summary not yet provided.)

Existing research: R&D ongoing at Stirling Biopower (www.stirlingbiopower.com/) and Stirling Danmark (www.stirling.dk).

Key research questions:

1. Questions not yet specified

Research to result in commercial materials & systems for direct conversion of thermal energy to electrical energy. (Summary not yet provided.)

Existing research: As of March 2012 roadmapping workshop participants indicated that there was ongoing R&D in this but did not specify where the R&D was being done.

Key research questions:

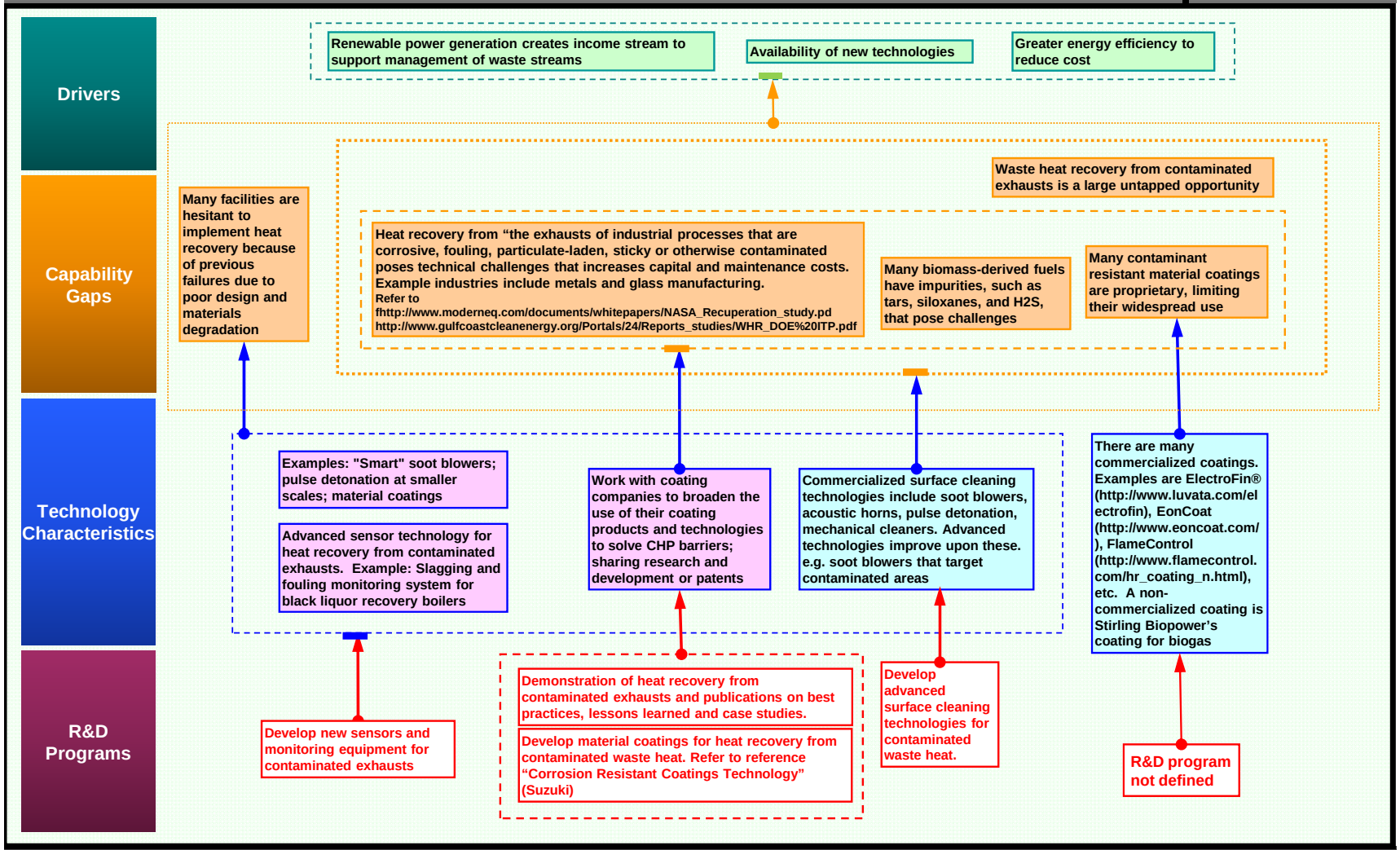
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Production (3 of 7)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Demonstration of heat recovery from contaminated exhausts and publications on best practices, lessons learned and case studies. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop advanced surface cleaning technologies for contaminated waste heat. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop new sensors and monitoring equipment for contaminated exhausts. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop material coatings for heat recovery from contaminated waste heat. Refer to Ichiro Suzuki, *Corrosion-Resistant Coatings Technology* (New York: Marcel Dekker [Taylor & Franicis Group], 1989)

Existing research: None identified.

Key research questions:

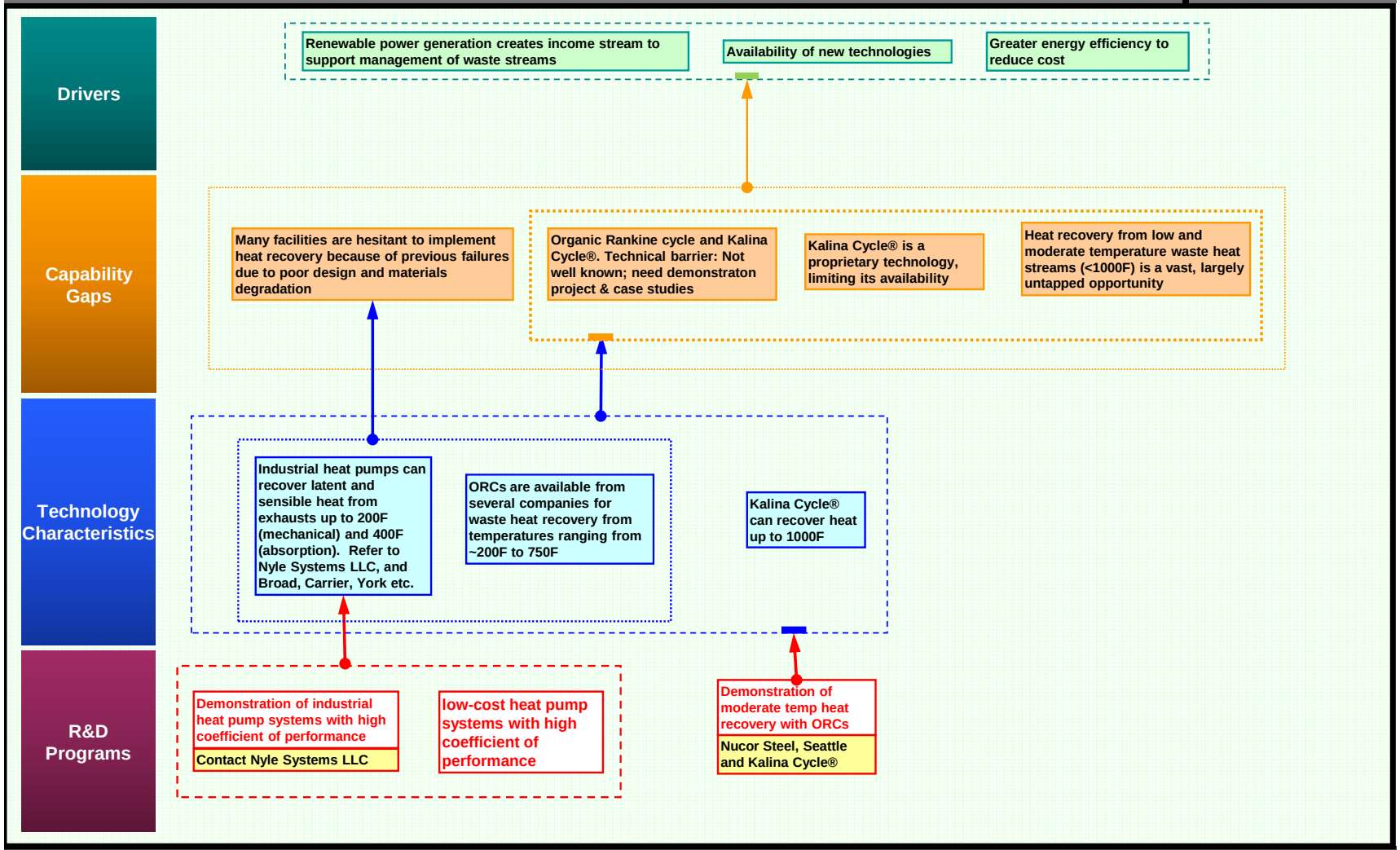
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Production (4 of 7)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Demonstration of industrial heat pump systems with high coefficient of performance. (Summary not yet provided.)

Existing research: For existing research, workshop participants suggested contact Nyle Systems LLC..

Key research questions:

1. Questions not yet specified

Demonstration of moderate temp heat recovery with Organic Rankine Cycles (ORCs). (Summary not yet provided.)

Existing research: For existing research, workshop participants suggested Nucor Steel, Seattle and Kalina Cycle®.

Key research questions:

1. Questions not yet specified

Low-cost heat pump systems with high coefficient of performance.

(Summary not yet provided.)

Existing research: None identified.

Key research questions:

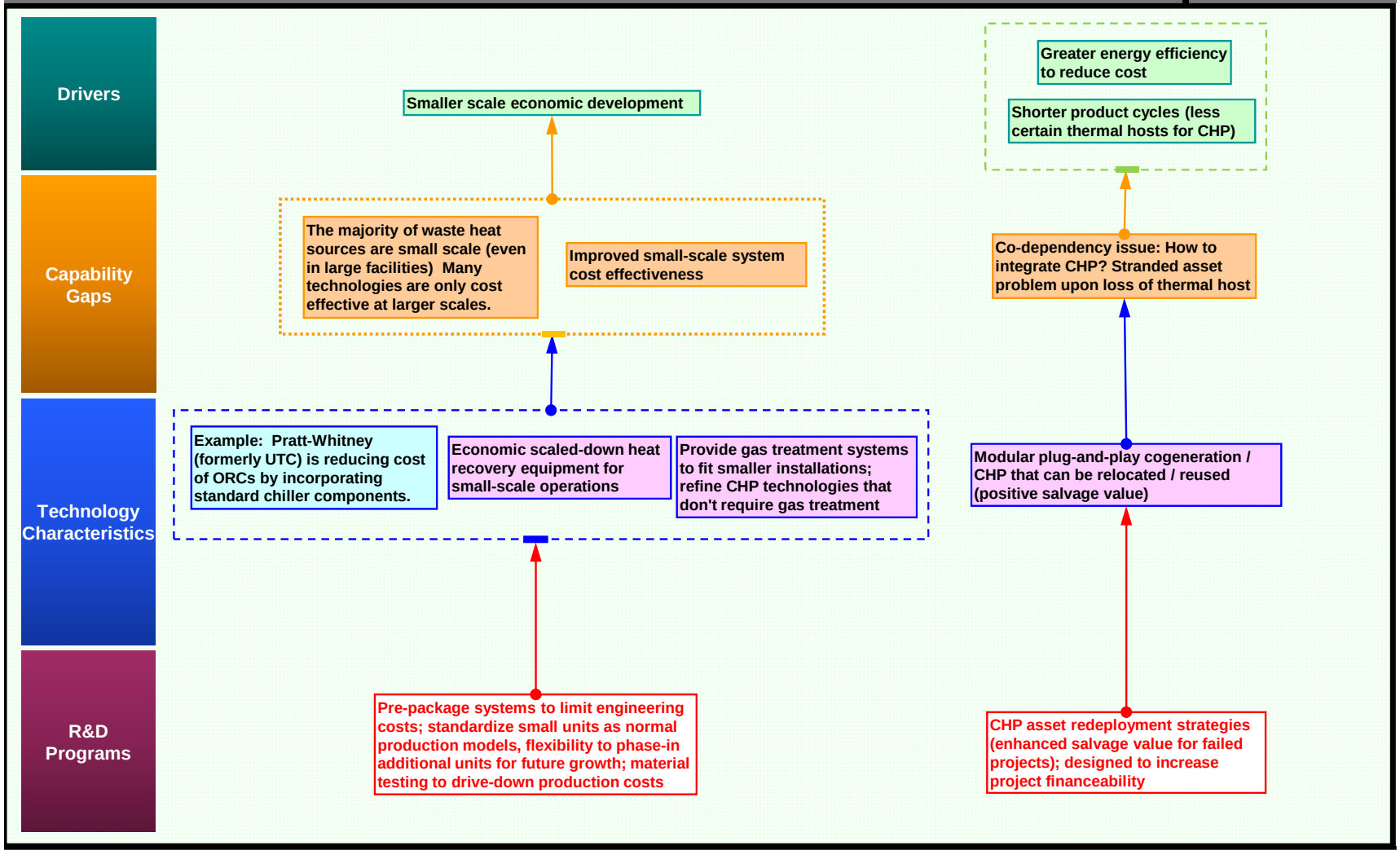
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Production (5 of 7)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

CHP asset redeployment strategies. Enhanced salvage value for failed projects designed to increase project financeability.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Pre-package systems. Limit engineering costs; standardize small units as normal production models, flexibility to phase-in additional units for future growth; material testing to drive-down production costs.

Existing research: None identified.

Key research questions:

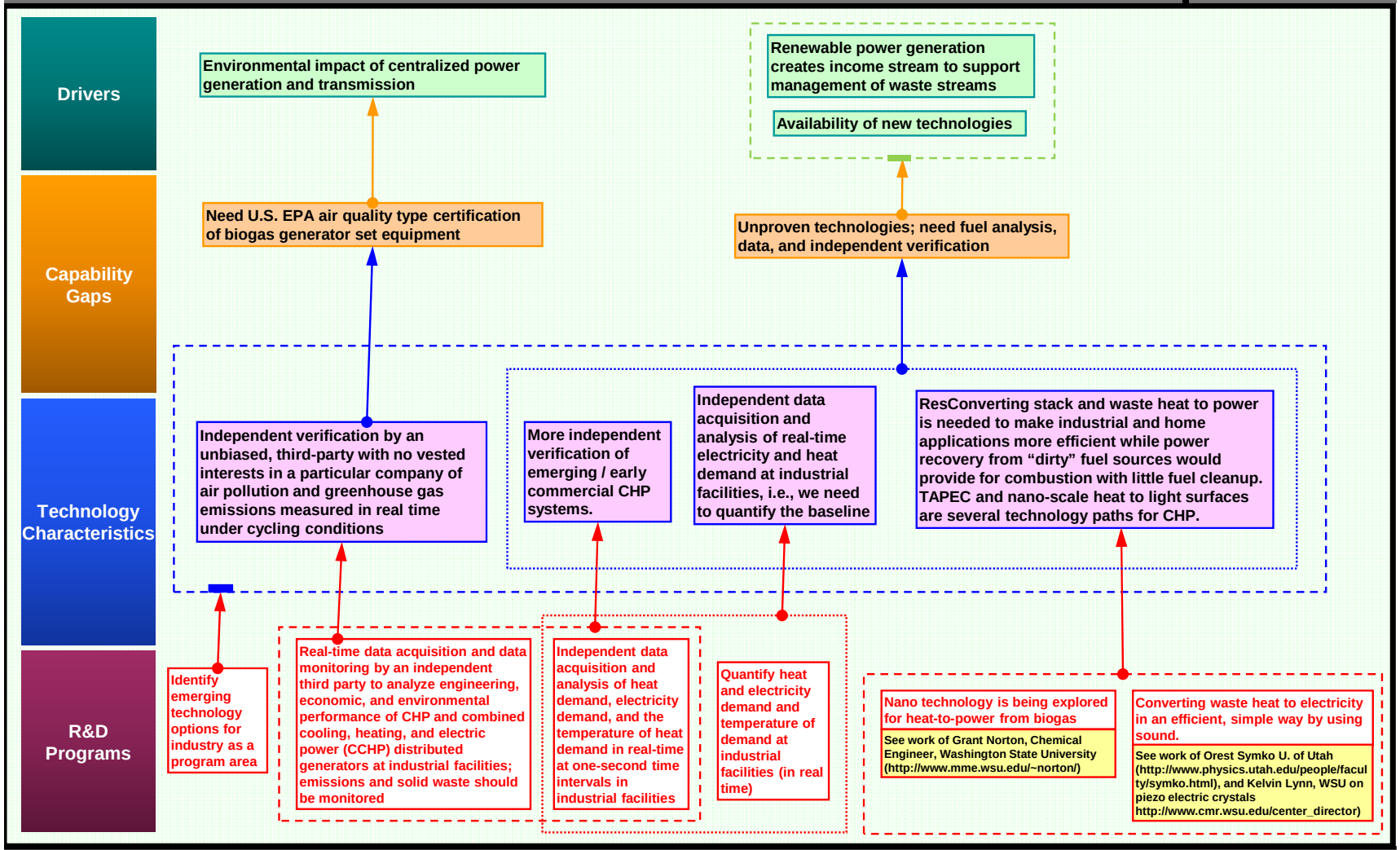
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Production (6 of 7)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Converting waste heat to electricity in an efficient, simple way by using sound.
Industrial settings such as stack heat using thermo acoustic piezo energy conversion (TAPEC) but also in home.

Existing research: See work of Orest Symko U. of Utah (http://www.physics.utah.edu/people/faculty/symko.html), and Kelvin Lynn, WSU on piezo electric crystals http://www.cmr.wsu.edu/center_director).

Key research questions:

1. Questions not yet specified

Nano technology is being explored for heat-to-power from biogas. (Summary not yet provided.)

Existing research: See work of Grant Norton, Chemical Engineer, Washington State University (http://www.mme.wsu.edu/~norton/).

Key research questions:

1. Questions not yet specified

Identify emerging technology options for industry as a program area. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Independent data acquisition and analysis of heat demand, electricity demand, and the temperature of heat demand in real-time at one-second time intervals in industrial facilities. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Real-time data acquisition and data monitoring. To be conducted by an independent third party to analyze engineering, economic, and environmental performance of CHP and combined cooling, heating, and electric power (CCHP) distributed generators at industrial facilities; emissions and solid waste should be monitored

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Quantify heat and electricity demand and temperature of demand at industrial facilities (in real time). (Summary not yet provided.)

Existing research: None identified.

Key research questions:

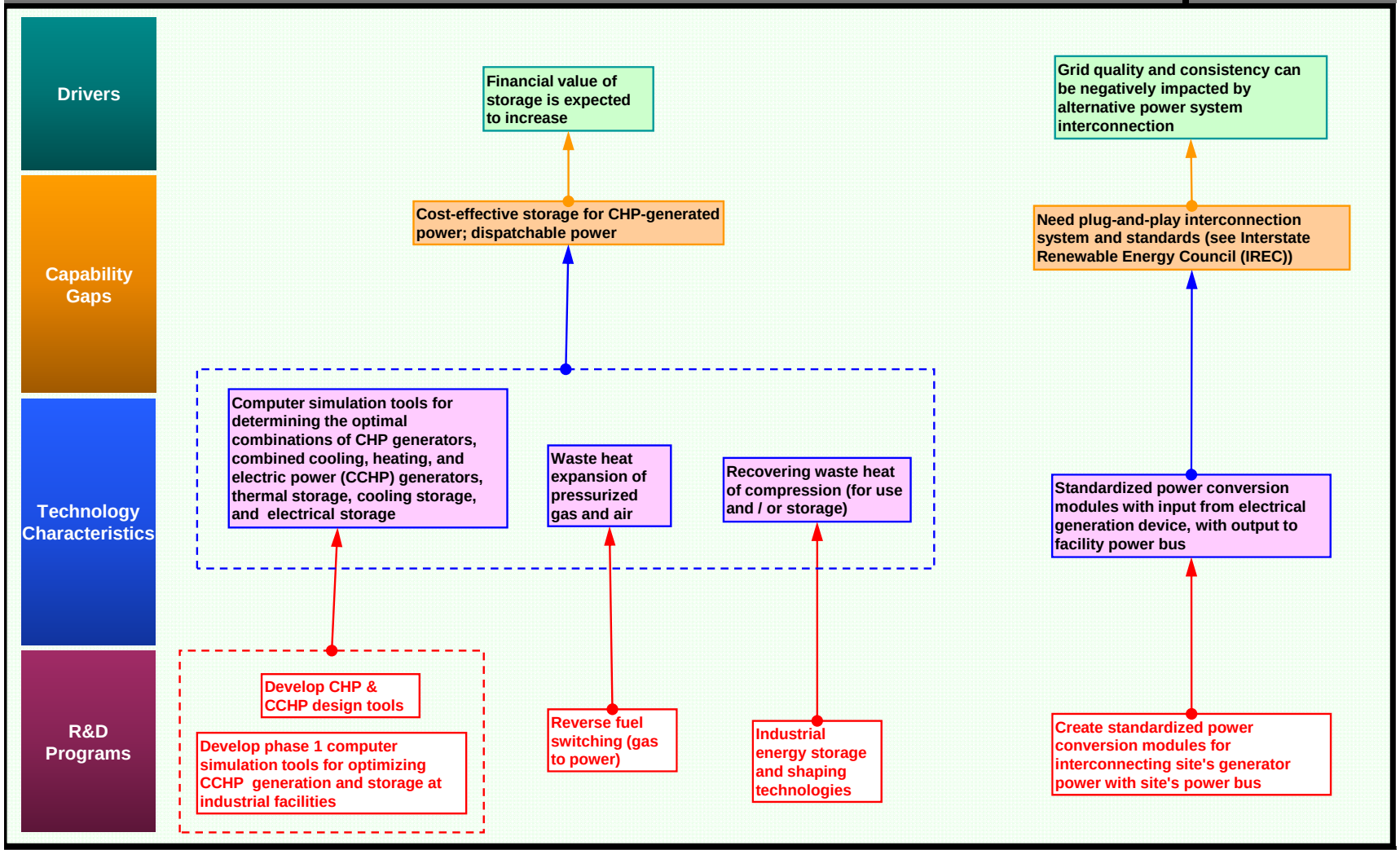
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Production (7 of 7)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Create standardized power conversion modules for interconnecting site's generator power with site's power bus. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop phase 1 computer simulation tools for optimizing CCHP generation and storage at industrial facilities. Computer simulation tools can identify optimal installed capacities, control strategies, and deployment and installation approaches for combined cooling, heating, and electric power (CCHP) systems; phase III models could be ultimately used by industry directly.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop CHP and CCHP design tools. Tools to be used by industry to select the optimal installed capacity of a CHP or combined cooling, heating, and electric power (CCHP) generator for a facility as well as optimal operating and control strategies

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Industrial energy storage and shaping technologies. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Reverse fuel switching (gas to power). (Summary not yet provided.)

Existing research: None identified.

Key research questions:

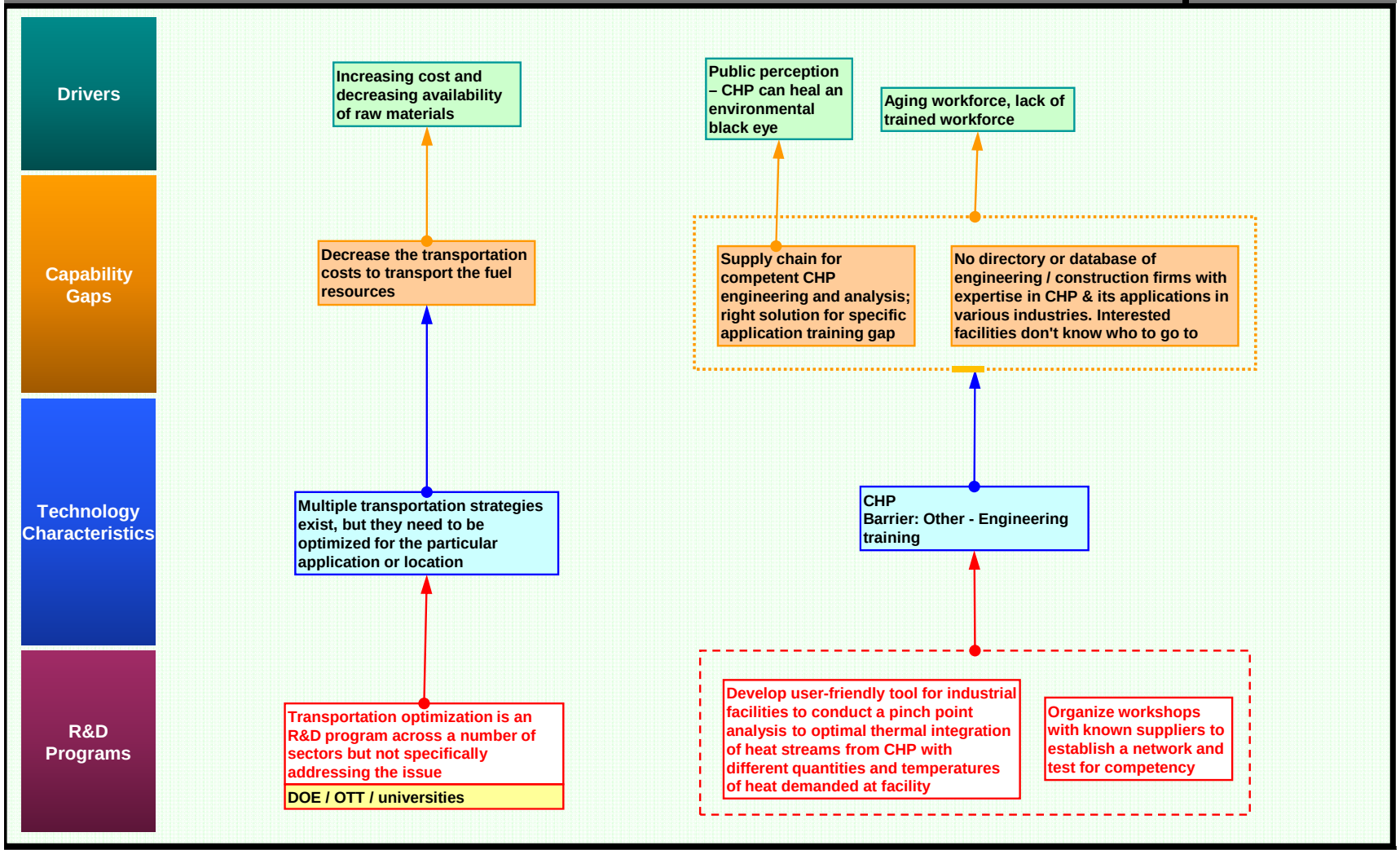
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Resources (1 of 7)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Transportation optimization. This R&D program applies across a number of sectors but these have not specifically addressed issues and concerns specific to industrial CHP systems.

Existing research: Stakeholders indicated ongoing research at the U.S. Department of Energy (DOE) and the DOE's Office of Transportation Technologies (OTT) within the Energy Efficiency and Renewable Energy (EERE), as well as at universities.

- DOE's Office of Transportation Technologies (OTT): http://www1.eere.energy.gov/vehiclesandfuels/

Key research questions:

1. Questions not yet specified

Develop user-friendly tool for industrial facilities to conduct a pinch point analysis to optimal thermal integration of heat streams from CHP with different quantities and temperatures of heat demanded at facility. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Organize workshops with known suppliers to establish a network and test for competency. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

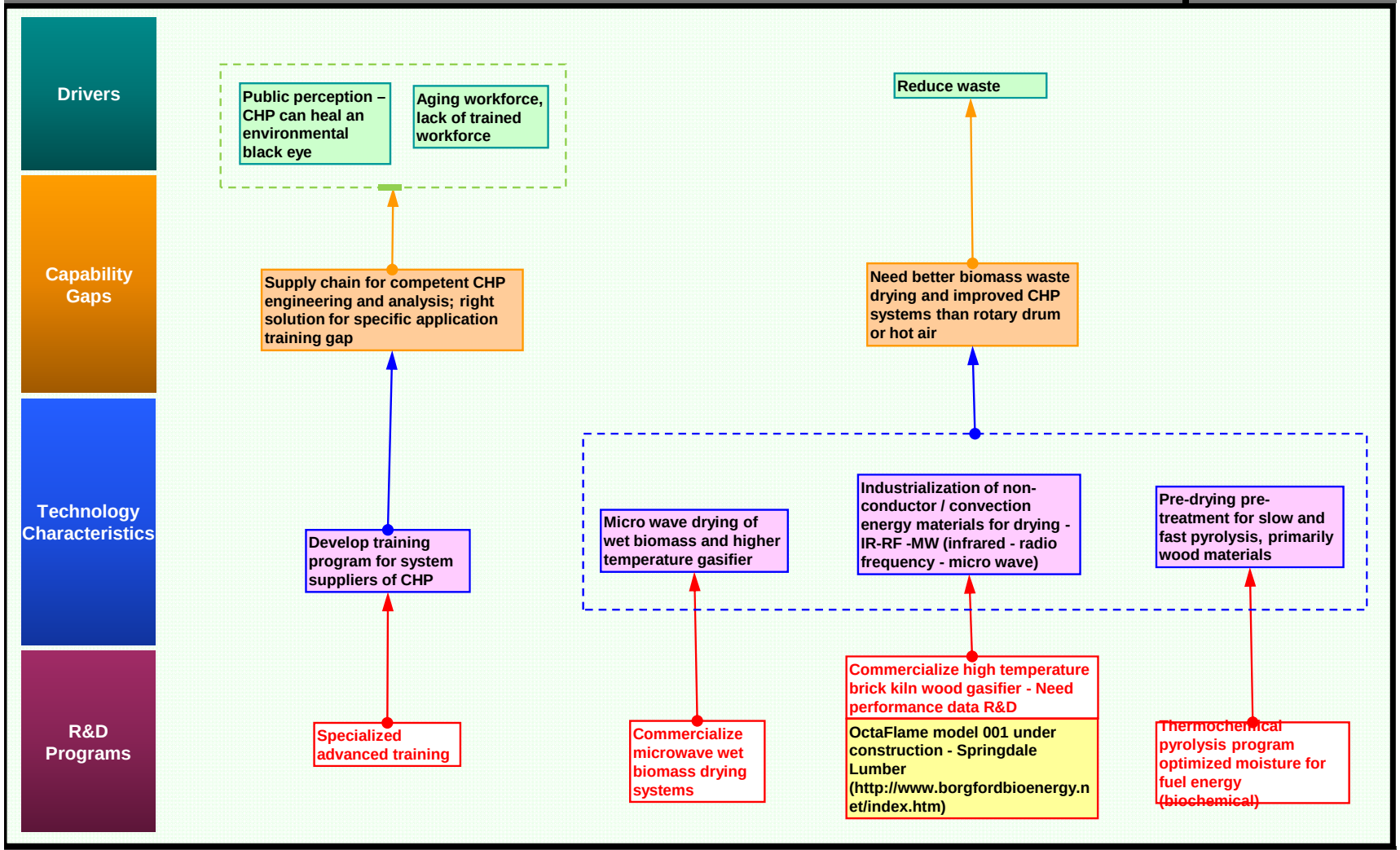
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Resources (2 of 7)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Commercialize high temperature brick kiln wood gasifier. Need performance data R&D on brick kiln wood gasifier system now being evaluated at Springdale Lumber in Spokane, Washington.

Existing research: Borgford BioEnergy LLC's OctaFlame model 001 is under construction at Springdale Lumber; see http://www.borgfordbioenergy.net/index.htm.

Key research questions:

1. Questions not yet specified

Specialized advanced training. Support and expand current programs to train graduates and post doctors for renewable industry with emphasis on new technology and ability to communicate complex ideas with the public.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Commercialize microwave wet biomass drying systems. For more information contact Rotawave Ltd. out of the U.K., rotawave.com.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Thermochemical pyrolysis program optimized moisture for fuel energy (biochemical). For more information contact Manuel Garcia Perez at Washington State University, www.bsyse.wsu.edu/garcia-perez.

Existing research: None identified.

Key research questions:

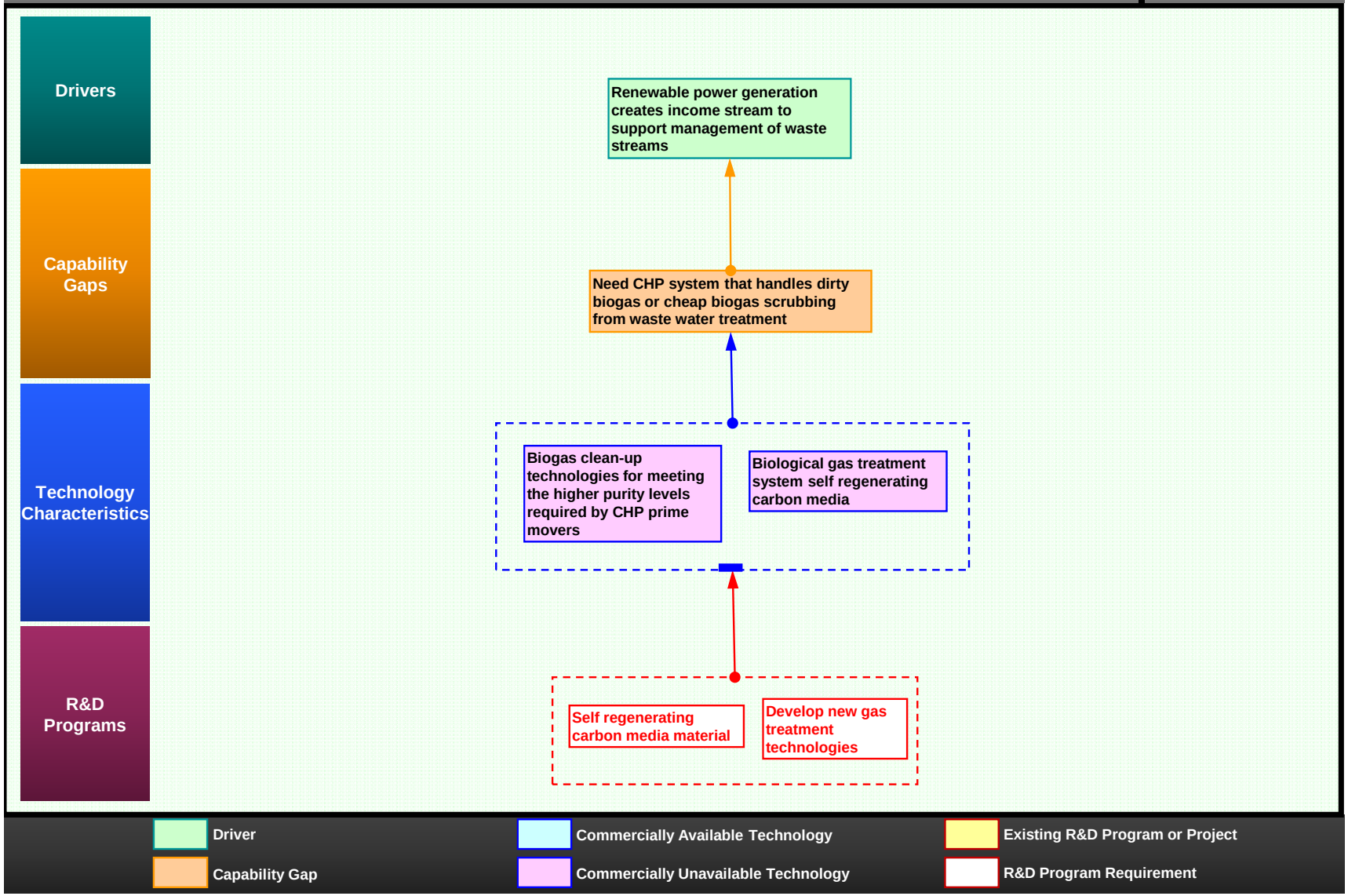
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Resources (3 of 7)**

See "Technology Area Definitions" section



R&D Program Summaries

Self regenerating carbon media material. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop new gas treatment technologies. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

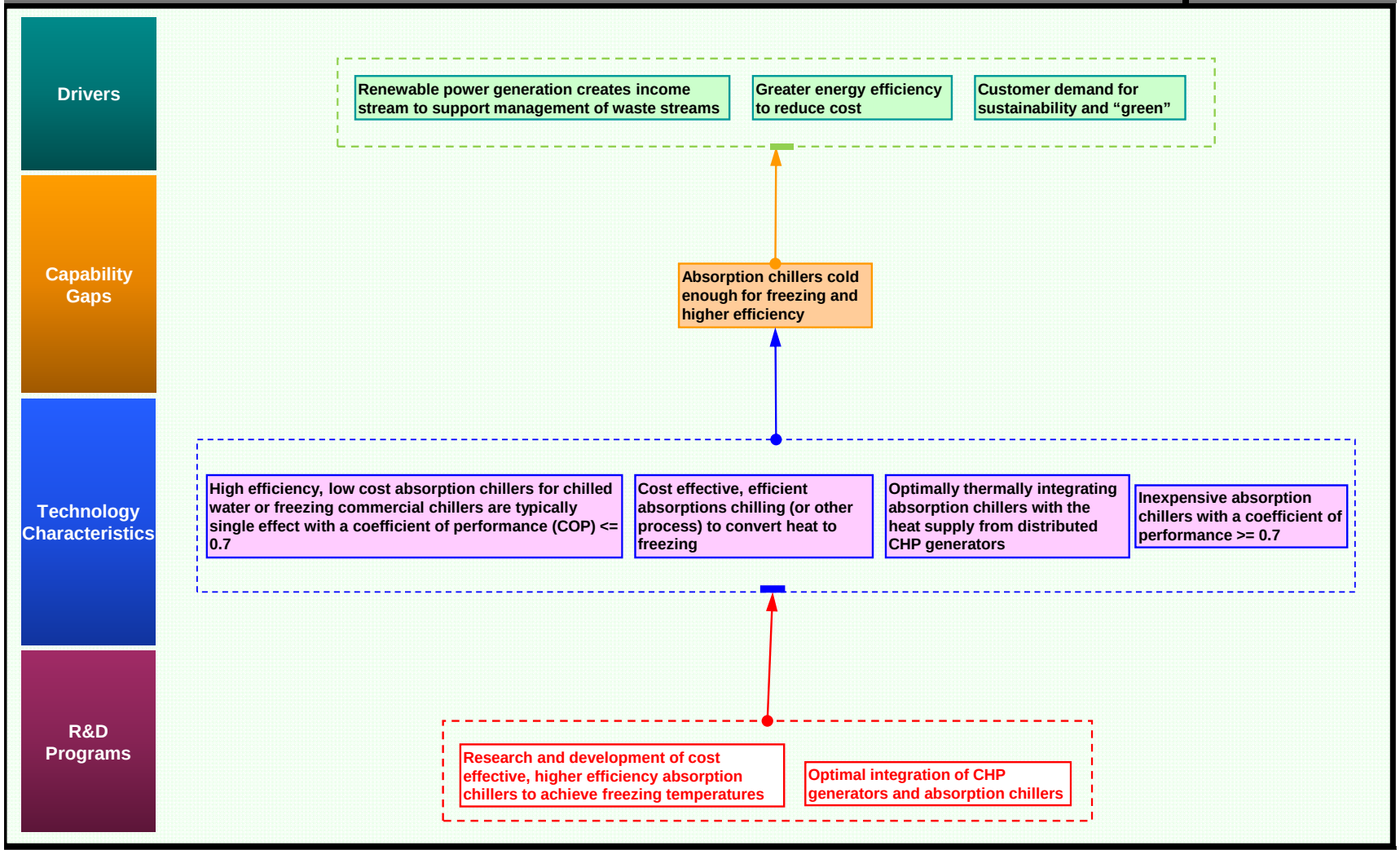
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Resources (4 of 7)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Cost effective, higher efficiency absorption chillers to achieve freezing temperatures. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Optimal integration of CHP generators and absorption chillers. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

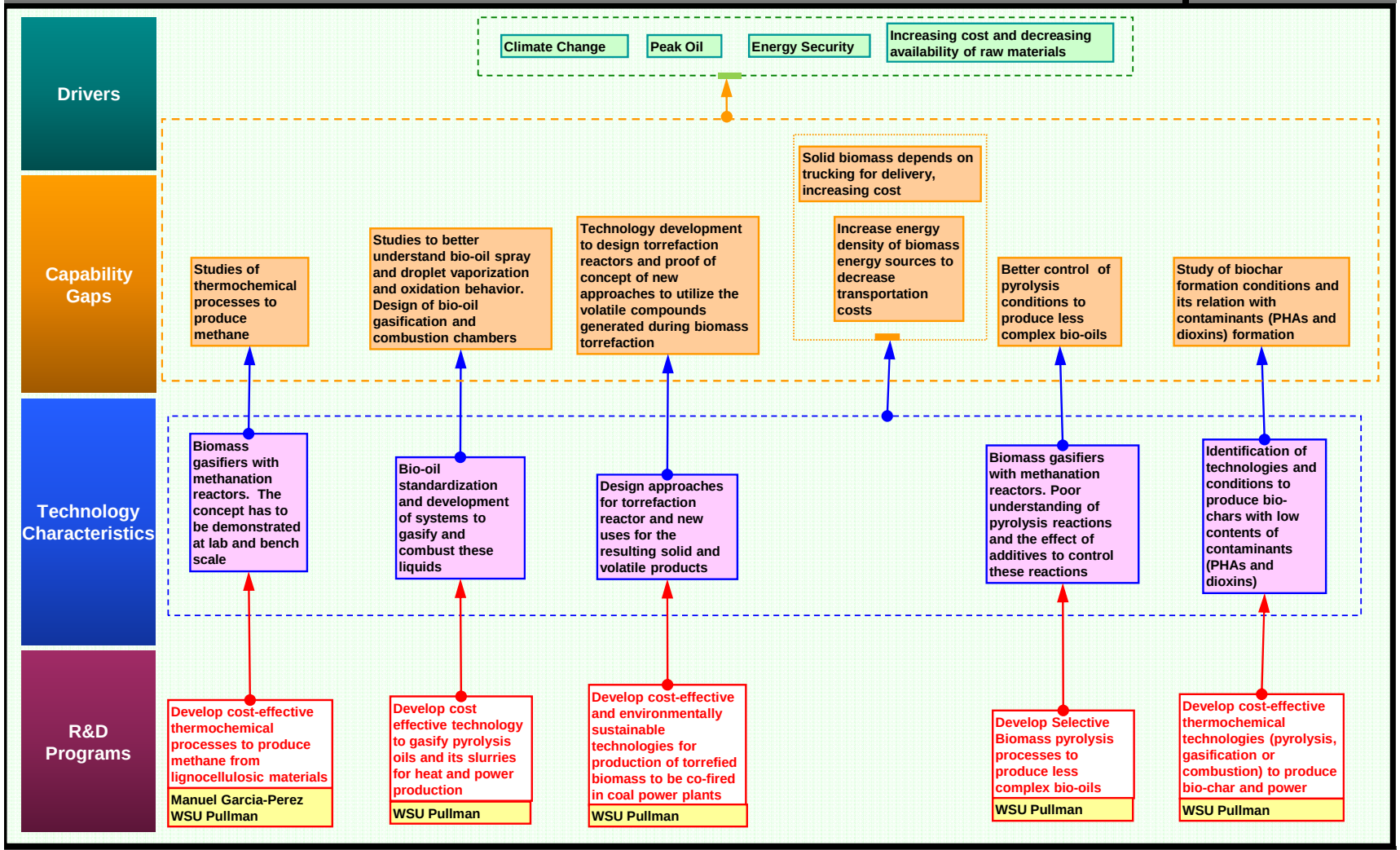
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Resources (5 of 7)**

See "Technology Area Definitions" section



R&D Program Summaries

Cost-effective and environmentally sustainable technologies for production of torrefied biomass to be co-fired in coal power plants. (Summary not yet provided.)

Existing research: Researchers at Washington State University (WSU) Center for Sustaining Agriculture and Natural Resources (CSANR)are conducting R&D about producing torrefied biomass; see http://csanr.wsu.edu/.

Key research questions:

1. Questions not yet specified

Cost-effective technology to gasify pyrolysis oils and its slurries for heat and power production. (Summary not yet provided.)

Existing research: Researchers at Washington State University (WSU) Center for Sustaining Agriculture and Natural Resources (CSANR)are conducting R&D about gasifying pyrolysis oils and its slurries; see http://csanr.wsu.edu/.

Key research questions:

1. Questions not yet specified

Cost-effective thermochemical processes to produce methane from lignocellulosic materials. (Summary not yet provided.)

Existing research: Contact Manuel Garcia Perez at Washington State University, www.bsyse.wsu.edu/garcia-perez.

Key research questions:

1. Questions not yet specified

Cost-effective thermochemical technologies (pyrolysis, gasification or combustion) to produce bio-char and power. (Summary not yet provided.)

Existing research: Researchers at Washington State University (WSU) Center for Sustaining Agriculture and Natural Resources (CSANR)are conducting R&D about producing bio-char and power using Cost-effective thermochemical technologies; see http://csanr.wsu.edu/.

Key research questions:

1. Questions not yet specified

Selective biomass pyrolysis processes to produce less complex bio-oils. (Summary not yet provided.)

Existing research: Researchers at Washington State University (WSU) Center for Sustaining Agriculture and Natural Resources (CSANR)are conducting R&D about producing less complex bio-oils from the pyrolysis processes; see http://csanr.wsu.edu/.

Key research questions:

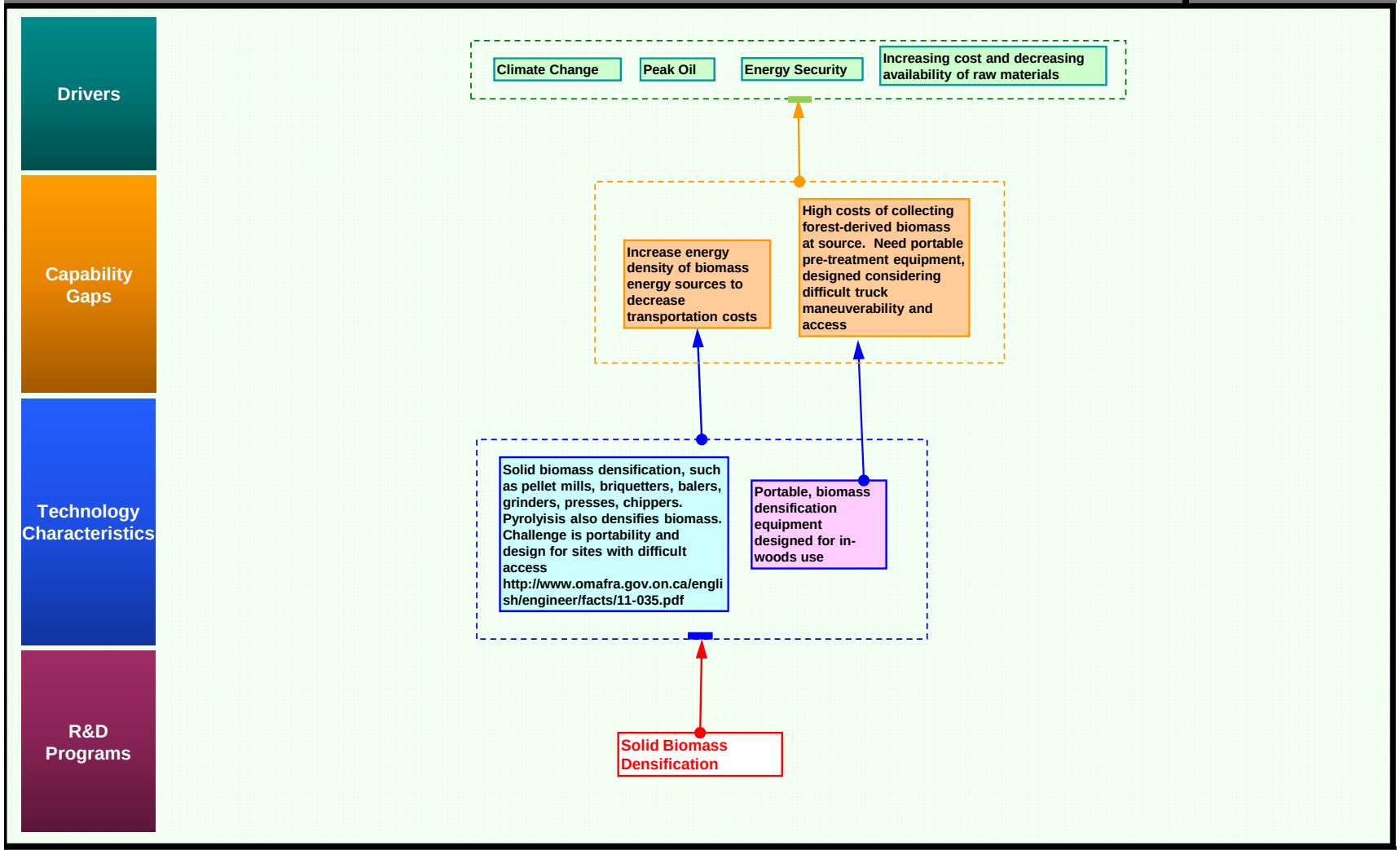
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Resources (6 of 7)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Solid biomass densification. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

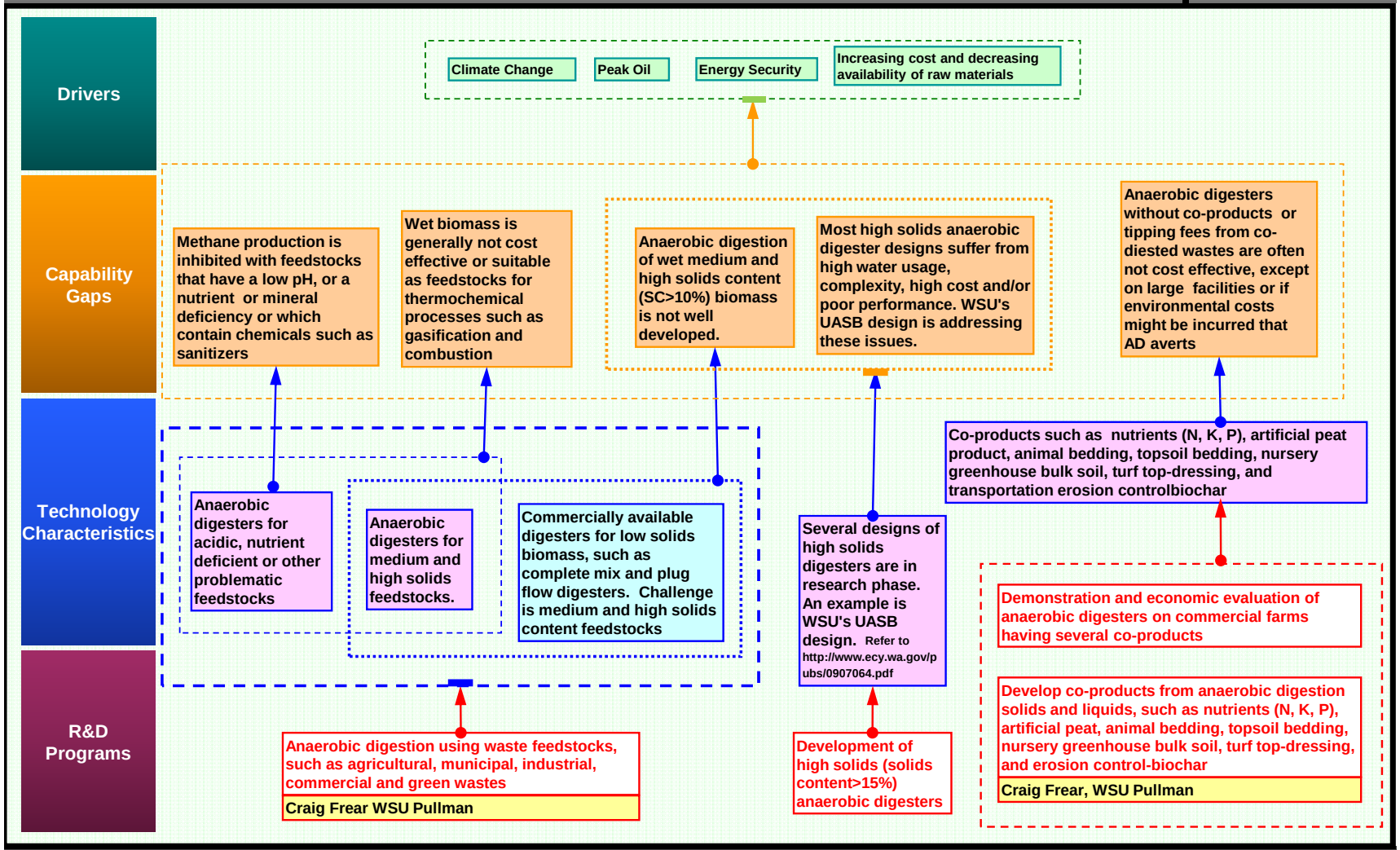
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Resources (7 of 7)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Anaerobic digestion using waste feedstocks. Digestion to include agricultural, municipal, inudstrial, commercial and green wastes.

Existing research: Contact Craig Frear, Washington State University, http://www.bsyse.wsu.edu/core/directory/faculty/cfrear.html.

Key research questions:

1. Questions not yet specified

Develop co-products from anaerobic digestion solids and liquids. Co-products to include nutrients (N, K, P), artificial peat, animal bedding, topsoil bedding, nursery greenhouse bulk soil, turf top-dressing, and erosion control-biochar.

Existing research: Contact Craig Frear, Washington State University, http://www.bsyse.wsu.edu/core/directory/faculty/cfrear.html.

Key research questions:

1. Questions not yet specified

Demonstration and economic evaluation of anaerobic digesters on commercial farms having several co-products. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Develop high solids (solids content >15%) anaerobic digesters. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

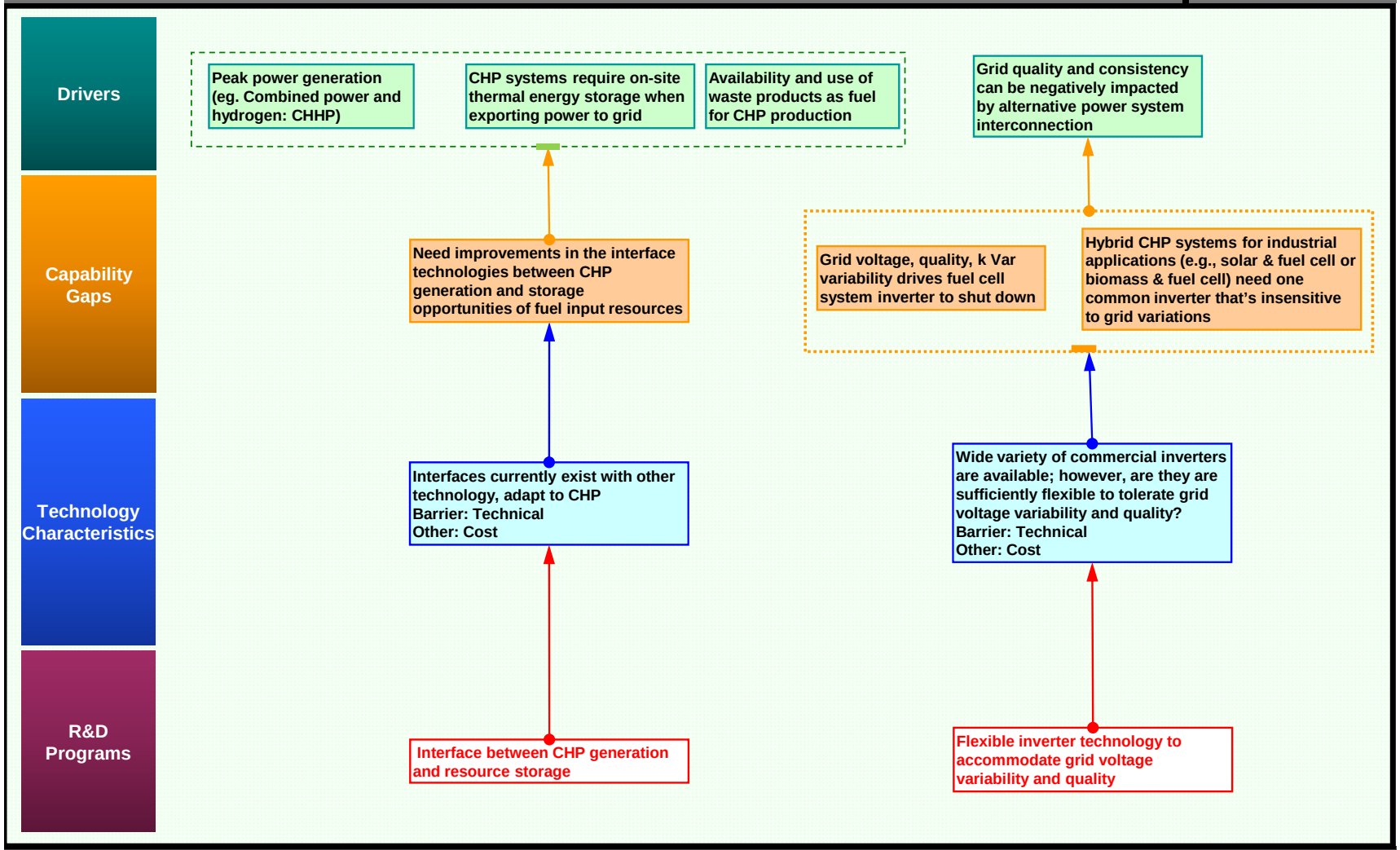
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Delivery (1 of 8)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Interface between CHP generation and resource storage. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Flexible inverter technology to accommodate grid voltage variability and quality. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

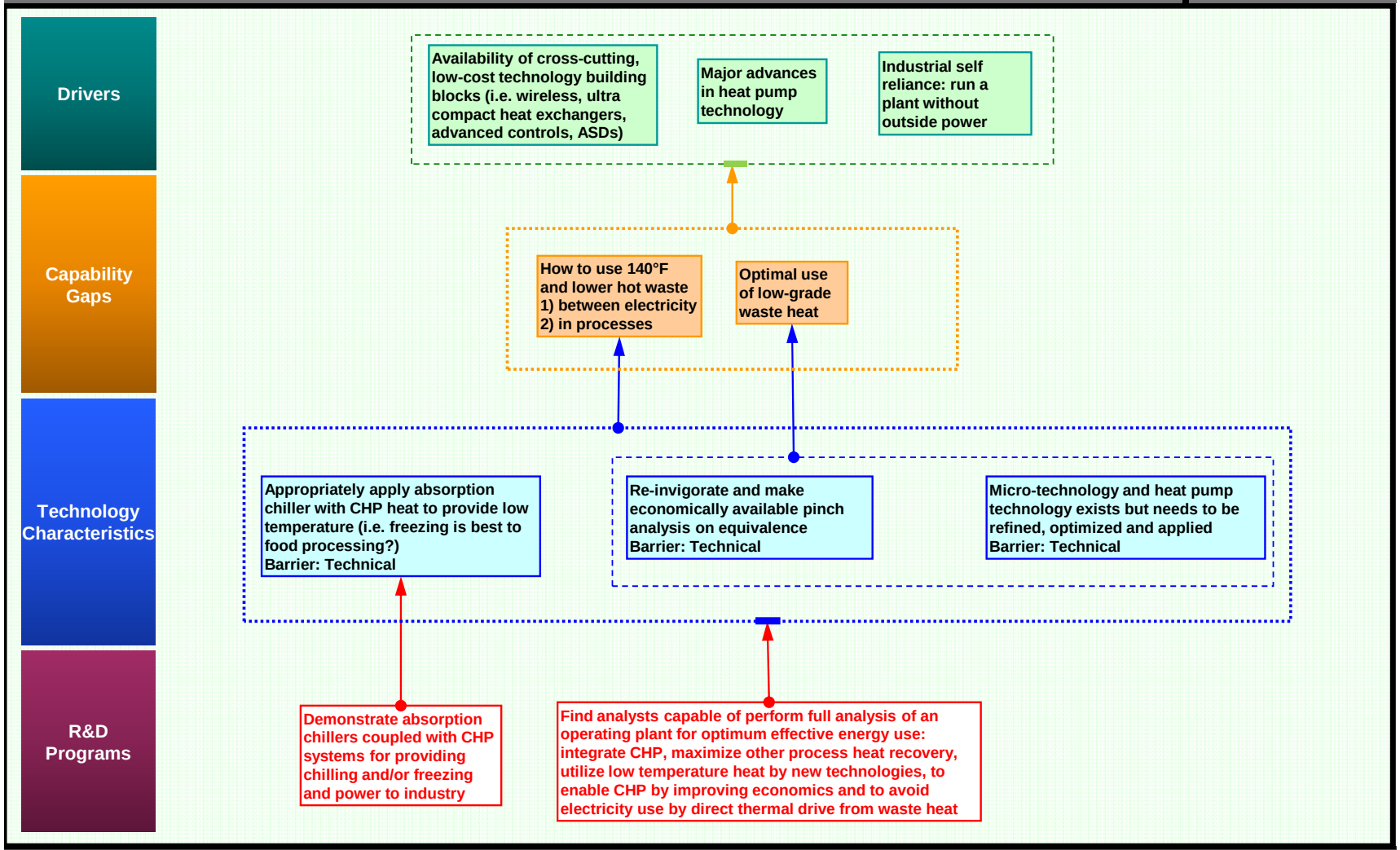
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Delivery (2 of 8)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Demonstrate absorption chillers coupled with CHP systems for providing chilling and/or freezing and power to industry. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Analysts capable of perform full analysis of an operating plant for optimum effective energy use. There is a need for qualified analysts to integrate CHP, maximize other process heat recovery, utilize low temperature heat by new technologies, to enable CHP by improving economics and to avoid electricity use by direct thermal drive from waste heat.

Existing research: None identified.

Key research questions:

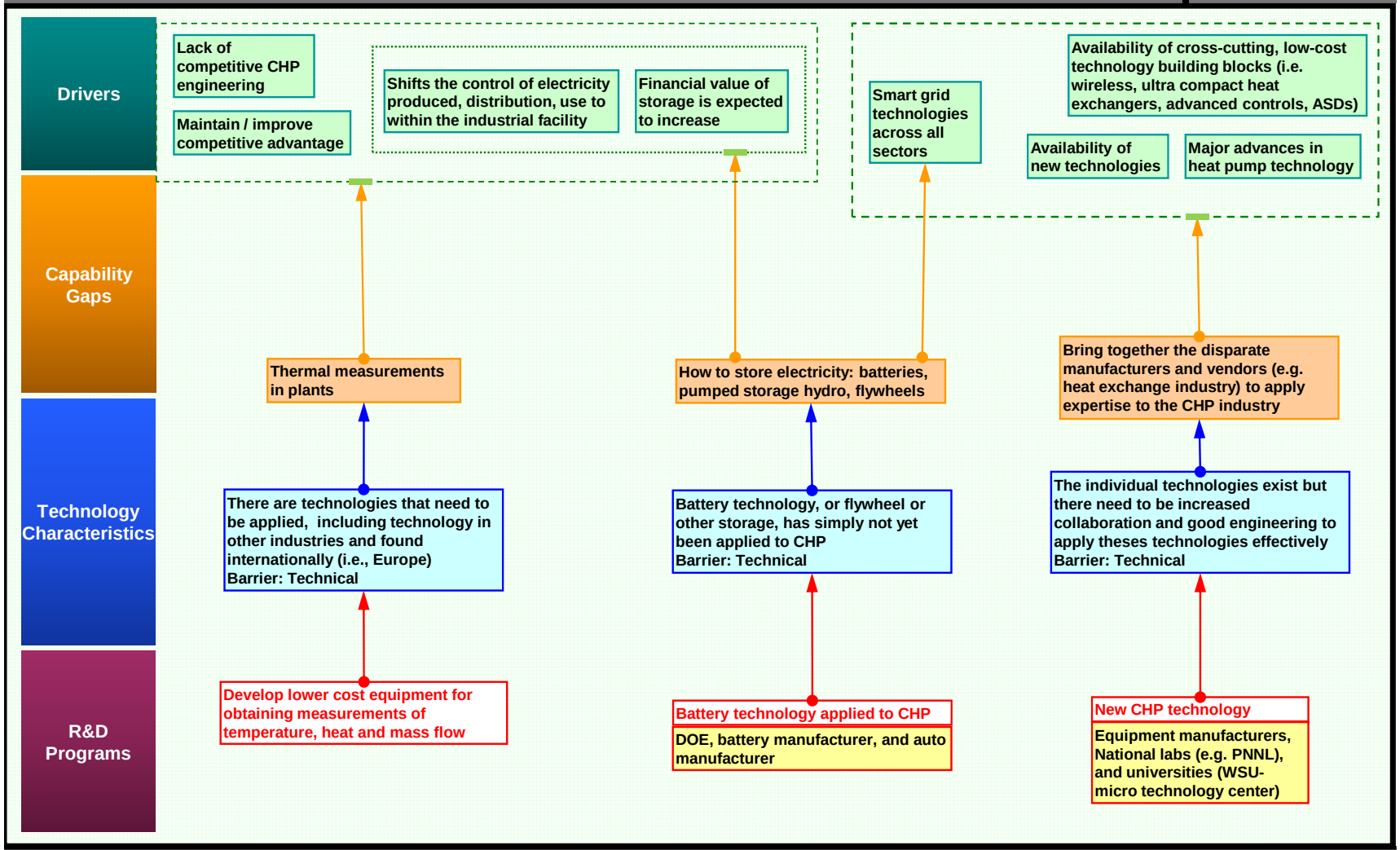
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Delivery (3 of 8)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Battery technology applied to CHP. There is much ongoing battery technology R&D but it is has not been directed at CHP applications (at least wide-spread).

Existing research: Research ongoing at the U.S. DOE, battery manufacturers, and auto manufacturers.

Key research questions:

1. Questions not yet specified

New CHP technologies. U.S. DOE and every major technology manufacturer is working on new technologies to fill this gap; the challenge is to bring these technologies to the CHP industry.

Existing research: Research ongoing at equipment manufacturers, National labs (e.g. PNNL), and universities (WSU-micro technology center).

Key research questions:

1. Questions not yet specified

Develop lower-cost equipment for obtaining measurements of temperature, heat, and mass flow. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

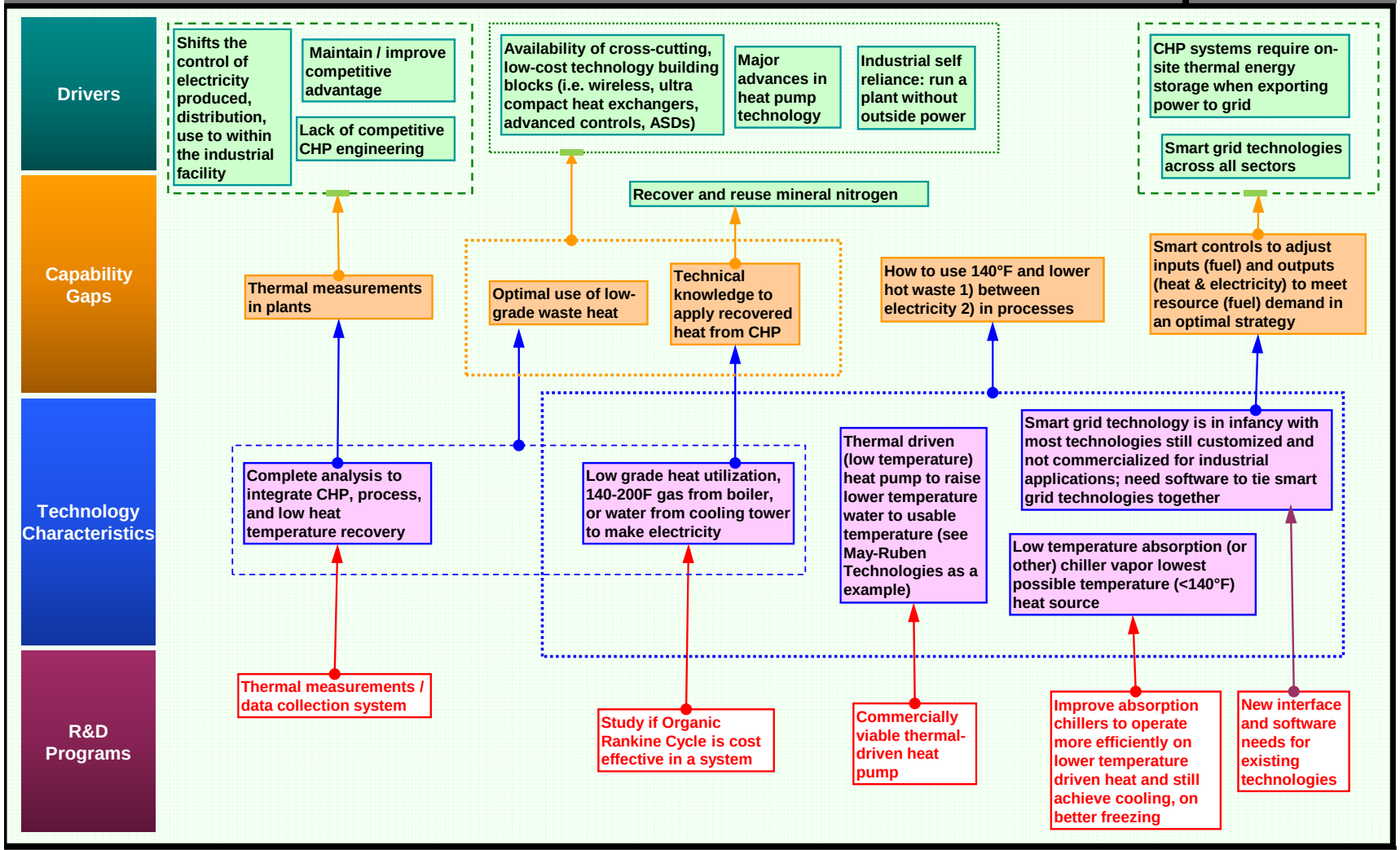
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Delivery (4 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Thermal measurements / data collection system. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Commercially viable thermal-driven heat pump. Need to lift low temperature (100°-140°F) heat to higher temperature (160°-200°F) so it can be utilized in process (reference: May-Ruben Technologies).

Existing research: None identified.

Key research questions:

1. Questions not yet specified

New interface and software for existing smart technologies. This could include smart technology for individual industrial equipment inside the plant linked to CHP system to give comprehensive ability to manage load and supply to meet price signals.

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Improve absorption chillers to operate more efficiently on lower temperature driven heat and still achieve cooling, on better freezing. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Study if Organic Rankine Cycle is cost effective in a system. Input = 140°F H2O or 170°F boiler exhaust gas, output = 50°F H2O or cool exhaust gas, and heat pump process producing electricity.

Existing research: None identified.

Key research questions:

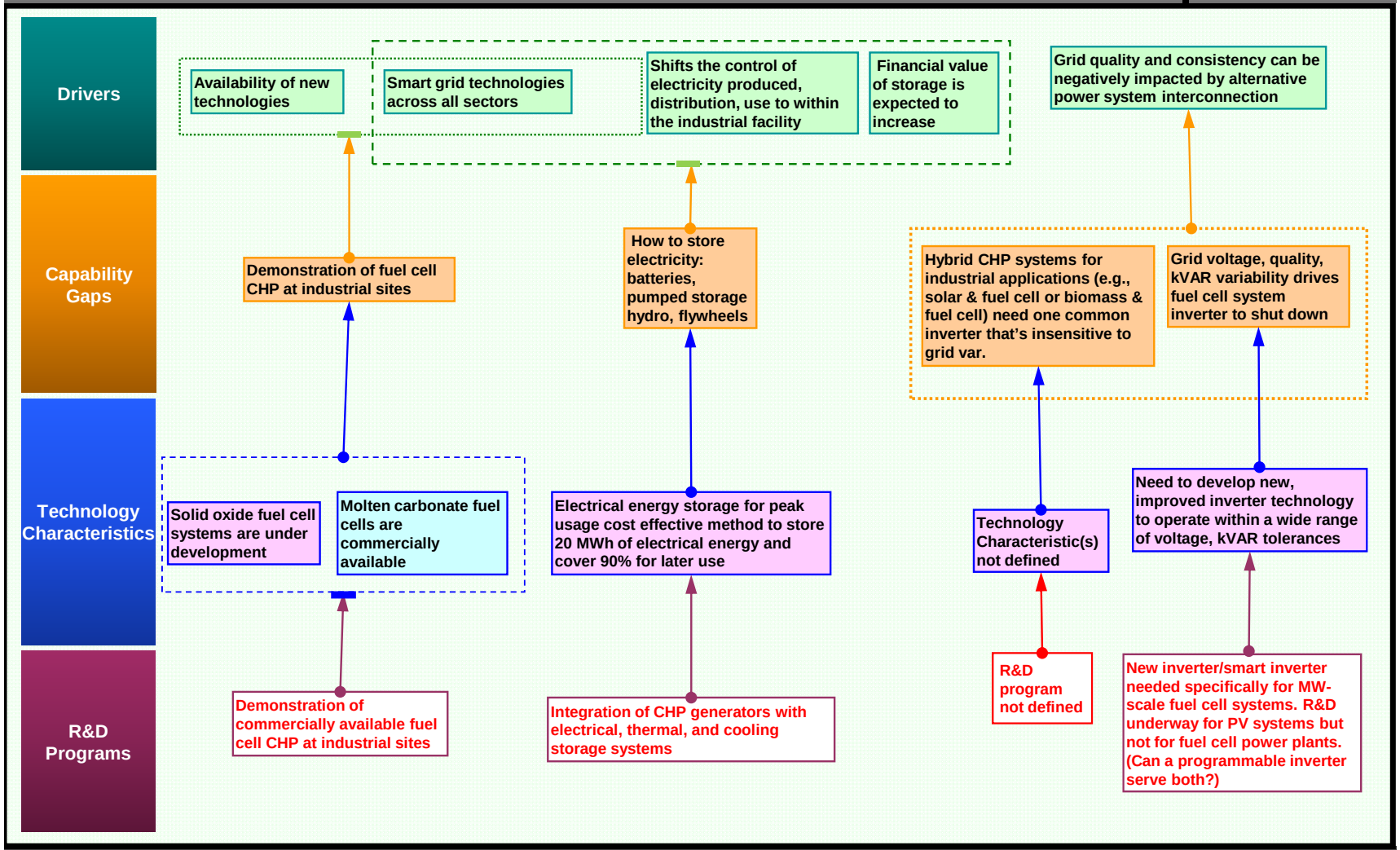
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Delivery (5 of 8)**

See "Technology Area Definitions" section



Driver	Commercially Available Technology	Existing R&D Program or Project
Capability Gap	Commercially Unavailable Technology	R&D Program Requirement

R&D Program Summaries

Demonstrate commercially-available fuel cell CHP at industrial sites. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Integrate CHP generators with electrical, thermal, and cooling storage systems. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

New inverter / smart inverter needed specifically for MW-scale fuel cell systems. R&D underway for photovoltaic (PV) systems but not for fuel cell power plants.

Existing research: None identified.

Key research questions:

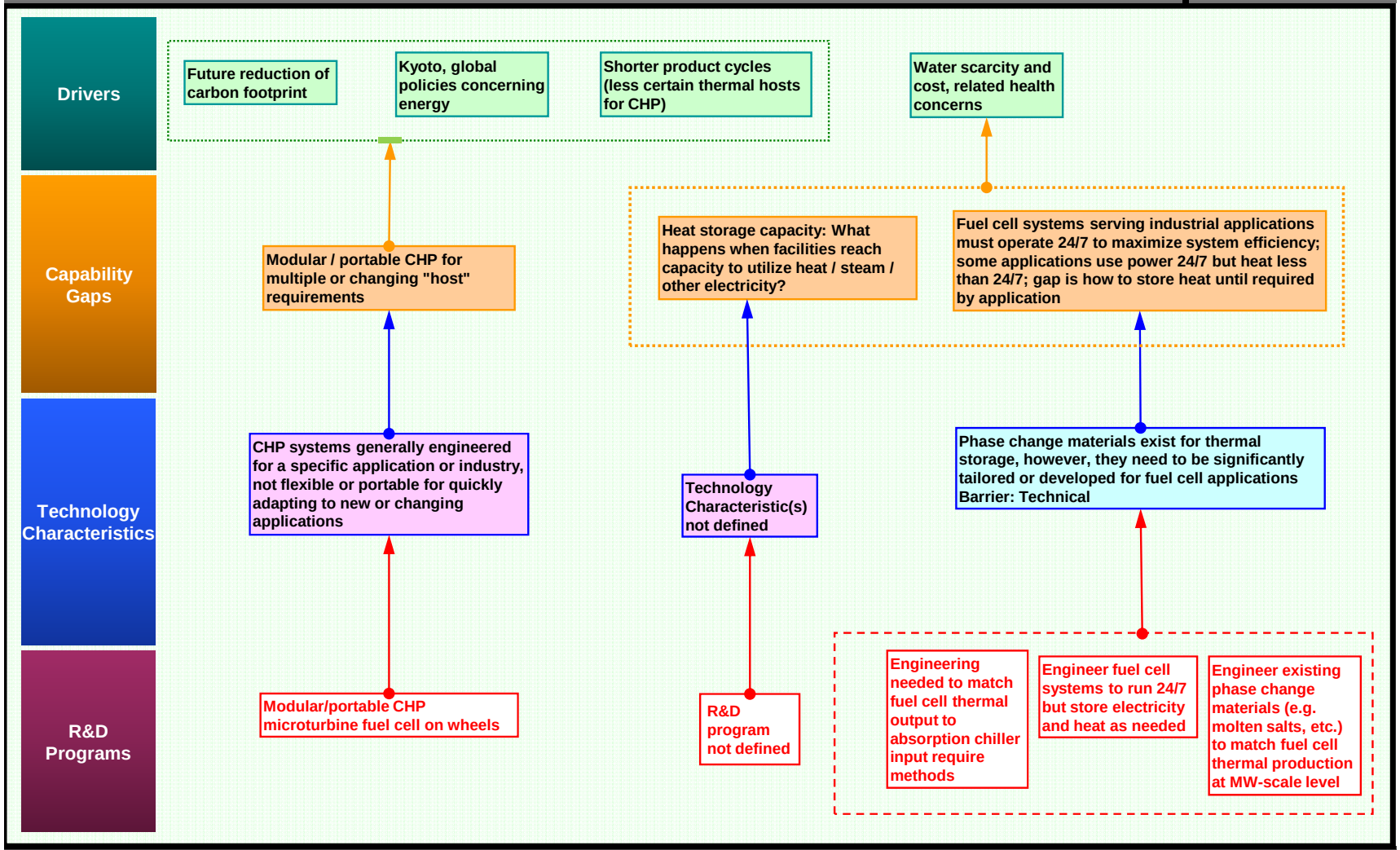
1. Can a programmable inverter serve both photovoltaic and MW-scale fuel cell systems?

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Delivery (6 of 8)**

See "Technology Area Definitions" section



Driver | Commercially Available Technology | Existing R&D Program or Project

Capability Gap | Commercially Unavailable Technology | R&D Program Requirement

R&D Program Summaries

Engineer existing phase change materials (e.g. molten salts, etc.) to match fuel cell thermal production at MW-scale level. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Engineer fuel cell systems to run 24/7 but store electricity and heat as needed. Engineer fuel cell systems to run 24/7 (to maximize efficiency), but store electricity and heat as needed when on-site applications do not require electricity or heat or both

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Engineering needed to match fuel cell thermal output to absorption chiller input require methods. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Modular / portable CHP microturbine fuel cell on wheels. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

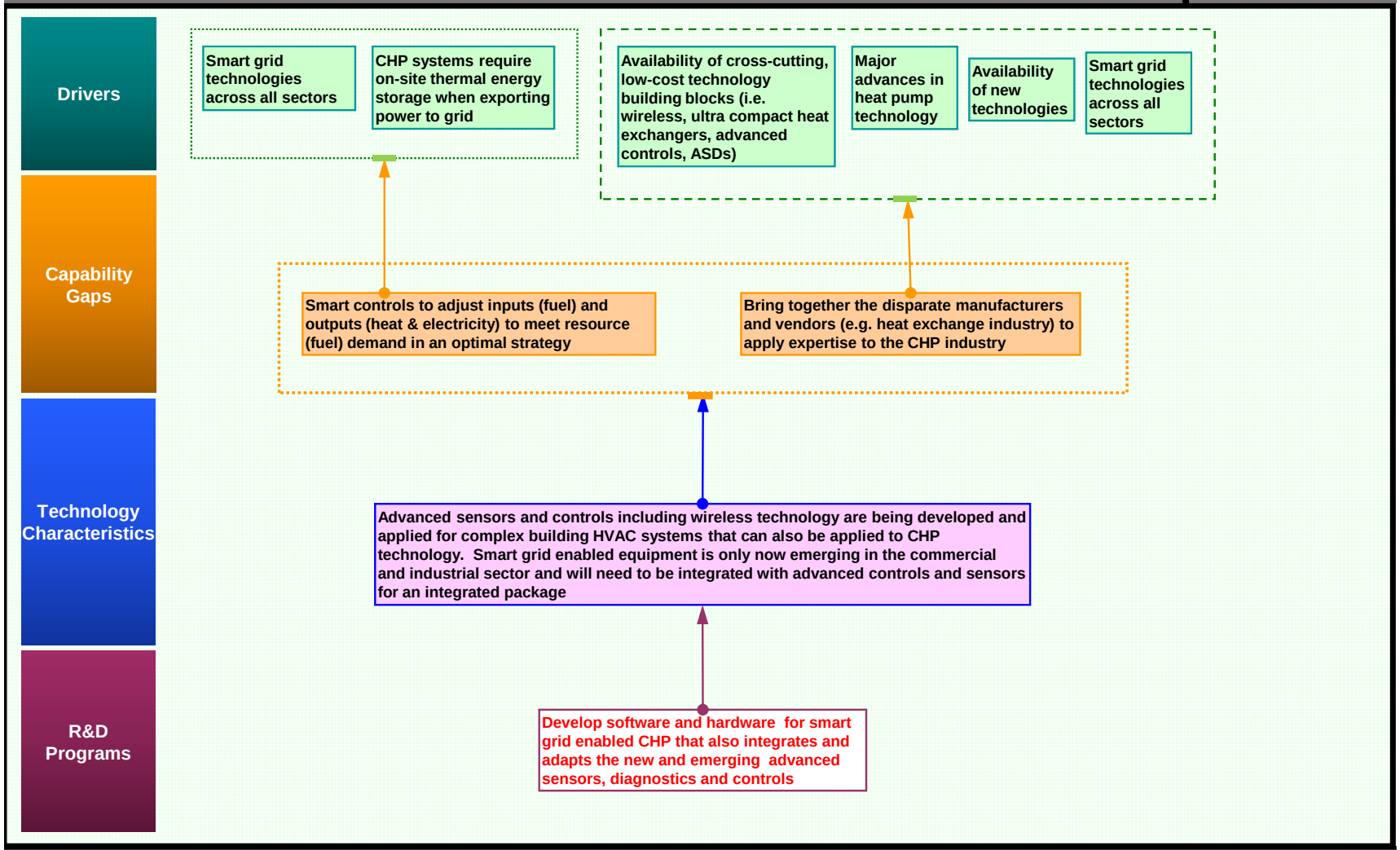
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Delivery (7 of 8)**

See "Technology Area Definitions" section



Driver | Capability Gap | Commercially Available Technology | Commercially Unavailable Technology | Existing R&D Program or Project | R&D Program Requirement

R&D Program Summaries

Develop software and hardware for smart grid-enabled CHP that integrates and adapts new and emerging advanced sensors, diagnostics, and controls. Develop software and hardware systems for CHP that is similar to advanced sensors, diagnostics and controls currently found in the HVAC industry for fans, pumps, motors, valves, etc.

Existing research: None identified.

Key research questions:

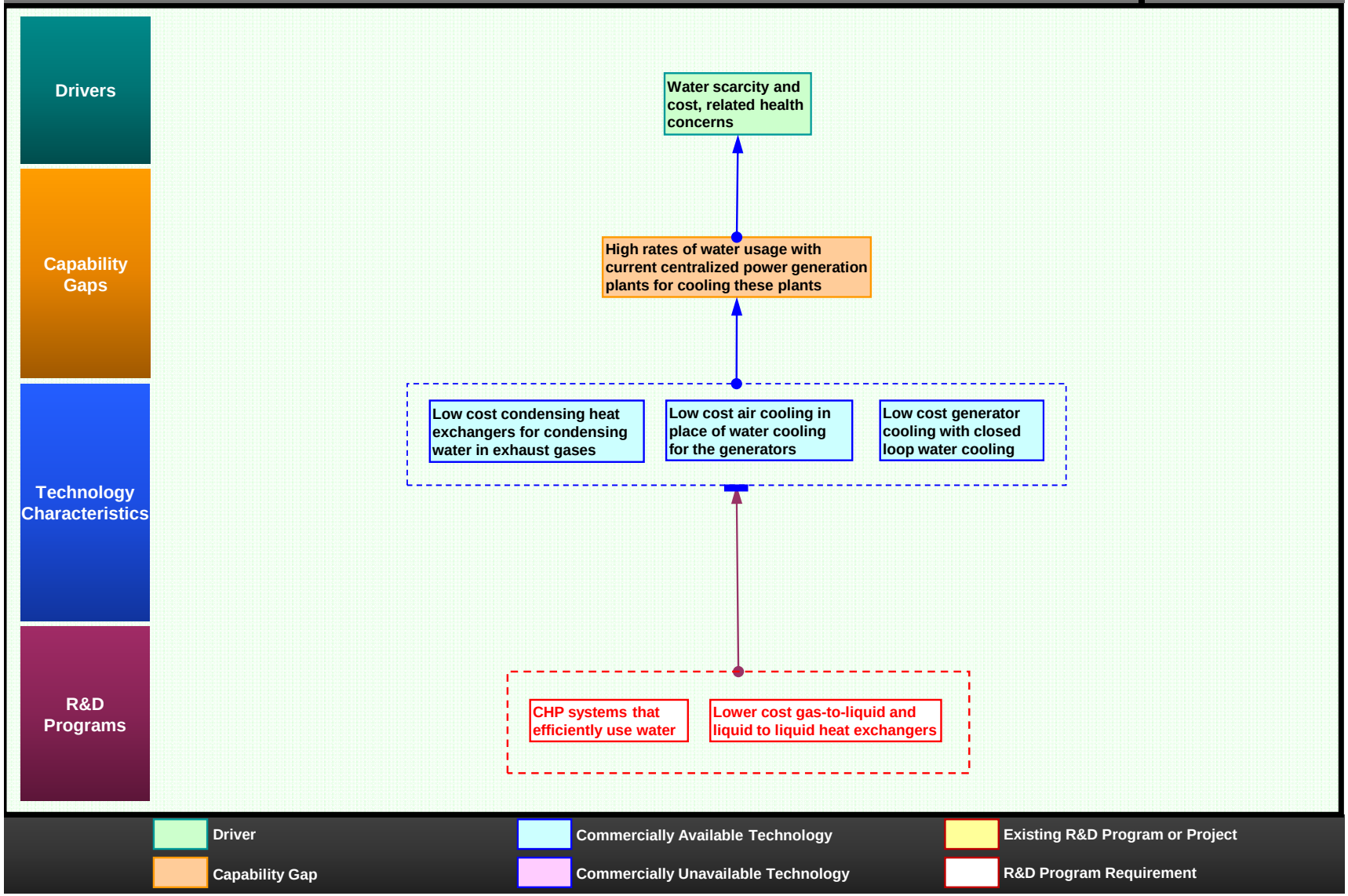
1. Questions not yet specified

Product/Service Area : **Combined Heat and Power (CHP)**

National Energy Efficiency Technology Roadmap Portfolio

Technology Roadmap: **Delivery (8 of 8)**

See "Technology Area Definitions" section



R&D Program Summaries

CHP systems that use water efficiently. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

1. Questions not yet specified

Lower cost gas-to-liquid and liquid to liquid heat exchangers. (Summary not yet provided.)

Existing research: None identified.

Key research questions:

2. Questions not yet specified